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Abundance, Migration Timing, and Biological Characteristics of Sockeye Salmon (*Oncorhynchus nerka*) Returning to Henderson Lake, Vancouver Island During 1988

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ABUNDANCE, MIGRATION TIMING, AND BIOLOGICAL CHARACTERISTICS OF SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) RETURNING TO HENDERSON LAKE, VANCOUVER ISLAND DURING 1988

by

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ABSTRACT

Tschaplinski, P.J. and K.D. Hyatt. 1990. Abundance, migration timing, and biological characteristics of sockeye salmon (*Oncorhynchus nerka*) returning to Henderson Lake, Vancouver Island during 1988. Can. Tech. Rep. Fish. Aquat. Sci. 1758: 82 p.

Several techniques were employed to estimate sockeye salmon escapements to Henderson Lake, Vancouver Island in 1988. The peak number of live-plus-dead sockeye observed during six visual surveys produced a minimum estimate of 19 634 fish. The highest estimates (78 226 and 80 963 sockeye) were derived respectively from simple and stratified Petersen mark-recapture techniques based upon recoveries of tagged carcasses. Intermediate estimates were generated from several other procedures including: (a) simple and stratified Petersen mark-recapture techniques based on counts of live, tagged fish; and, (b) the area under a spawner abundance curve (AUC) combined with separate estimates of mean spawner residence time determined from cumulative tag-day methods, tag-depletion regressions (adjusted for tag-detection efficiency), and the interval between peak counts of live and dead spawners. Comparisons among population assessment techniques showed that most intermediate estimates were biased high. The AUC method plus an 18-day spawner residence time generated the preferred population estimate of 38 302 fish.

Sockeye arrived at the Henderson Lake and Clemens Creek spawning grounds around 15 September. Spawning was initiated between that date and 30 September, peaked by 30 October, and was completed by 23 November. Five-year-old fish (age 1.2) composed 69.3% of the population; four-year-olds (age 1.3) formed 30.1%, and six-year-olds (age 1.4) formed only 0.6%. Males and females within the same age classes were not significantly different in mean length (all $p>0.05$): four-year-old males and females were respectively 442.3 and 445.1 mm long on average. Five-year-old males and females, both significantly larger than four-year-olds ($p<0.05$), were respectively 503.9 and 499.3 mm long on average. Males and females formed 50.9 and 49.1% of escapement samples respectively; however, 79.5% of age 1.2 fish were females, while 58.8% of age 1.3 fish were males.

RÉSUMÉ

Tschaplinski, P.J. and K.D. Hyatt. 1990. Abundance, migration timing, and biological characteristics of sockeye salmon (*Oncorhynchus nerka*) returning to Henderson Lake, Vancouver Island during 1988. Can. Tech. Rep. Fish. Aquat. Sci. 1758: 82 p.

Plusieurs techniques ont été utilisées pour évaluer les échappées de saumon rouge vèrs le lac Henderson (île de Vancouver) en 1988. Le nombre maximal de saumons rouges vivants et morts observés au cours de six relevés visuele a été estimé à au moins 19 634 poissons. Les estimations les plus fortee (78 226 et 80 963 saumons rouges) ont été obtenues à partir respectivement des méthodes de Petersen, simple et stratifiée, de marquage et de recapture fondées sur la récupération de carcasses marquées. Des estimations intermédiaires ont été obtenues à partir de plusieurs autres techniques, notamment: (a) des méthodes de Petersen, simple et stratifiée, de marquage et de recapture reposant sur le dénombrement de poissons vivants marqués; (b) la surface sous la courbe d'abondance d'un géniteur combinée à des estimations distinctes du temps de séjour moyen d'un géniteur calculé à partir de méthodes de collecte quotidienne cumulative d'étiquettes, de régressions de l'épuisement des étiquettes (corrigées pour tenir compte de l'efficacité du dépistage des étiquettes), et de l'intervalle entre les dénombrements maximaux de géniteurs vivants et morts. D'après les comparaisons des techniques d'évaluation des populations, la plupart des estimations intermédiaires ont été biaisées à la hausse. La méthode de la surface sous la courbe plus un temps de séjour de 18 jours du géniteur a permis d'estimer la population choisie à 38 302 poissons.

Les saumons rouges ont atteint les frayères du lac Henderson et du ruisseau Clements vers le 15 septembre. La fraye a commencé entre cette date et le 30 septembre, a atteint sa période de pointe le 30 Octobre, et elle a pris fin le 23 novembre. Les poissons âgés de cinq ans (Age 1.2) représentaient 69,3 % de la population, les poissons âgés de quatre ans (âge 1.3) constituaient 30,1 % de la population, et les poissons âgés de six ans (âge 1.4) ne représentaient que 0,6 % de la population. La longueur moyenne des mâles et des femelles de la même classe d'âge ne différait pas de façon significative (toutes les $p>0,05$): les mâles et les femelles âgés de quatre ans mesuraient en moyenne, respectivement 442,3 et 445,1 mm de longueur. Les mâles et les femelles âgés de cinq ans, les deux étant significativement plus grande que les poissons âgés de quatre ans ($p<0,05$) mesuraient en moyenne, respectivement 503,9 et 499,3 mm de longueur. Les mâles et les femelles représentaient respectivement 50,9 et 49,1 % des échantilions de l'échappée toutefois, 79,5 % des poissons d'âge 1.2 étaient des femelles tandis que 58,8 % des poissons d'âge 1,3 étaient des mâles.

INTRODUCTION

The commercial net fishery for sockeye salmon (Oncorhynchus nerka Walbaum) in Statistical Area 23, Barkley Sound, Vancouver Island intercepts fish bound for Great Central, Sproat, and Henderson lakes (Steer et al. 1986, Steer and Hyatt 1987). The Barkley Sound sockeye fishery depends entirely upon these three stocks; moreover, these fish now comprise most of the sockeye catch from the west coast of Vancouver Island (about 87 % of the total catch between 1969 and 1986). These fish are taken principally by a large fleet of commercial purse seine and gillnet vessels which usually operate in Area 23 from mid-June through July (Hyatt and Steer 1987; Steer et al. 1986). The growth of this fishery has been well documented (Hyatt and Steer 1987), and is due partly to net increases in adult sockeye production resulting from fertilization of the three sockeye nursery lakes tributary to Barkley Sound.

Fertilization was initiated at Great Central Lake between 1970 and 1973 as a sockeye enhancement technique (Lebrasseur et al. 1978, Hyatt et al. 1985). Great Central Lake has been fertilized annually since 1977, Henderson Lake since 1976, and Sproat Lake between 1985 and 1986 (Hyatt and Steer 1987).

The Biological Sciences Branch, Canada Department of Fisheries and Oceans is responsible for determining the effects on sockeye production of annual additions of inorganic nutrients to coastal lakes. Data combining information on annual spawning escapements, commercial catches, and smolt production (numbers, size distributions, and survival) have been collected for Henderson Lake between 1980 and 1988 under conditions of lake fertilization. This information has several important applications including the determination of (i) escapement levels that maximize smolt production under a regime of lake fertilization, (ii) whether sockeye production from Henderson Lake during years when fertilization occurred exceeds that commonly observed for sockeye originating from unfertilized systems, and (iii) the effectiveness of within-season management procedures in achieving escapement goals for Henderson Lake sockeye (Hyatt and Steer 1989).

Given the multiple applications for reliable escapement data, adult sockeye salmon returning to Great Central, Sproat, and Henderson lakes have been enumerated and sampled annually according to standardized procedures since 1980 to determine their age, sex, and length distributions.

The Henderson Lake sockeye stock is the smallest one in Area 23. Between 1980 and 1987, Henderson Lake sockeye annually formed only 2.1 - 16.9 % of the total sockeye escapements in Area 23 and 0 - 15 % of the commercial net catch. Because of the small size of this stock, it is especially vulnerable to overfishing. Accordingly, most fishing effort is usually directed at the larger and earlier returning Great Central and Sproat Lake stocks which appear in Barkley Sound in May and begin their migrations upstream by late May - early June (Hyatt and Steer 1987). The later returning Henderson Lake stock first appears in Barkley Sound in late June - mid-July, enters Henderson Lake usually in September, and begins migrating upstream in Clemens Creek, the main tributary to the lake, generally in late September (Fig. 1).

Most sockeye in the Henderson Lake system spawn in the lower 6.5 - 7.0 km of Clemens Creek, while some spawners use lakeshore reaches adjacent to the mouth of both Clemens and Ternan creeks (Fig. 2). Seasonal estimates of sockeye escaping to Henderson Lake have been made on the spawning grounds through either simple visual surveys (1980) or visual counts combined with Petersen mark-recapture techniques (Ricker 1975, Seber 1982). Simple Petersen estimates were made annually from 1981 - 1985, while stratified Petersen estimates were also employed for enumerations in 1986 and 1987. Visual counts of spawners made seasonally at different intervals provided an alternative to the Petersen estimates. However, poor visibility associated with high discharge volumes and turbidity in Clemens Creek have biased such counts to underestimate spawning populations in most years. Adverse environmental conditions require that several techniques be employed each year to estimate the abundance of sockeye spawners in the Henderson Lake system because no single procedure can always be depended upon to provide an accurate estimate.

Between 1980 and 1987, 95 - 300 sockeye were collected annually from the spawning populations in the Henderson Lake system to determine their age, sex, and length distributions (Steer et al. 1988). Seasonal samples were taken commonly in two to three weekly collections consisting usually of 100 fish each (range: 8 - 101).

The objectives of the 1988 escapement studies at Henderson Lake were to employ a variety of methods to estimate the numbers of sockeye spawning in the system and to obtain representative samples of spawners to accurately describe some of the biological characteristics of that population. Accordingly, the present report details the procedures employed to determine (a) the size of the sockeye spawning escapement to Henderson Lake and Clemens Creek in 1988 and (b)

the length-frequency, age, and sex composition of the spawners. Methods for the determination of the biological characteristics of the spawning population were consistent with those employed between 1980 and 1987 (Steer et al. 1988). Separate estimates of population numbers were generated from: (i) simple visual counts of live and dead sockeye made at intervals on the spawning grounds during September - November; (ii) Petersen mark-recapture techniques employing sequential applications and subsequent visual enumerations of color-coded disc tags over the same months; and, (iii) a spawner abundance curve calculated from visual counts of live spawners made during surveys combined with three independent estimates of mean spawner residence time. All estimates were evaluated with respect to strengths and biases.

MATERIALS AND METHODS

Population Estimates

Migration Onto the Spawning Grounds, Spawning Activity, and Visual Counts of Live Sockeye

Six visual surveys of sockeye escapements to Henderson Lake and Clemens Creek were made in 1988 between 29 September and 30 November. During each survey, observations were made on spawning activity and the distribution of adult sockeye in both the stream and the lake. The date when sockeye first arrived on the spawning grounds was extrapolated from the numbers counted in the system during the first four survey dates which spanned 1 - 30 October. Sockeye numbers were extended to zero based upon the mean daily change in abundance during October. The final date of spawning was similarly approximated from numbers counted on the two last trips of the year.

Two types of visual counts were employed to provide independent estimates of spawner abundance in Clemens Creek. One method involved counting all spawners visible along the lakeshore near the mouth of Clemens Creek and throughout seven equally spaced reaches of the lower 7.0 km of the stream (Fig. 2). Two full days were generally required to complete each survey by this technique due to the restricted daylight hours available during October and November. The second method, termed strip counting, has been employed each year between 1983 and 1985, and again in 1988 to augment total-section counts. All sockeye observed in a variable number of one-

meter wide strips across each section of Clemens Creek were counted. The strip counting method enables stream surveys to be easily completed in one day during October and November.

For each total-section survey, two observers walked along the main channel and any secondary channels. Each observer employed hand-held, mechanical counters to enumerate all sockeye visible. Sockeye were counted individually whenever possible; otherwise, groups of fish were estimated numerically in multiples of fives, tens, and hundreds. Cumulative counts from each observer were recorded for each section. The average between sums obtained separately by the two observers was accepted as the total count for each main-channel reach. Counts from secondary channels obtained by either observer were added to the main-channel averages to determine total sockeye abundance in each section. All live sockeye carrying color-coded, Petersen disc tags were tallied separately and the numbers of each color code were recorded for each stream section. Adult salmon of other species were also counted on all surveys.

Stream sections were counted sequentially from the uppermost (section 7) to section 1 located at the mouth of Clemens Creek. Both tagged and untagged sockeye occurring along the beach adjacent to the mouth of Clemens Creek were counted by observers passing parallel to the shoreline in a small boat equipped with a 9.9-horsepower outboard motor. The boat was driven slowly (< 0.5 m/s) to avoid disturbing the fish. All sockeye sighted between the lakeshore and the 3 - 5-m depth limit of visibility were tallied.

All sections of the stream were examined on each survey of the spawning grounds except for the trip of 29 October when heavy rains caused high flows and turbidity in Clemens Creek. Only sections 5, 6, and 7 could be counted during that survey. Counting was suspended after poor visibility associated with rapidly increasing discharge made visual observations impossible. Heavy rain also prevented visual counts of sockeye along the lakeshore.

In addition to the six main visual surveys, sockeye in sections 1 - 6 of Clemens Creek were enumerated again on 25 October to compare strip-count and total-section methods. To estimate the abundance of live spawners by the strip-count method, sockeye were censused within strips spaced at 33.5-m intervals along the entire length of each stream section. Strips were consecutively numbered and counted beginning at the upstream end of each reach. Between 19 and 36 strips were counted per section. For each section, the sum of all fish counted was divided by the number of strips surveyed to determine sockeye density. The resulting value of number of fish per lineal meter was then multiplied by the length of

each reach (m) to derive the sectional population estimates. Population numbers obtained by strip-count and total-section methods were compared: the speed and relative accuracy of the strip counting technique could then be evaluated.

Monitoring Physical Conditions in the Lake and Stream

Accurate visual counts of sockeye spawners could be obtained only when streamflows were relatively low and stable. Therefore, stream and lake levels were monitored during each population survey from staff gauges installed at the lakeshore adjacent to the field camp and in sections 1 and 5 of Clemens Creek. The lakeside gauge, painted on the face of a large boulder, has been maintained in the same location and position since 1980.

The gauge in section 5, secured to a streamside tree roughly 20 m upstream from a bridge, has remained in place since first installed in 1987. However, the gauge in section 1 was lost during a freshet prior to the beginning of the 1988 escapement surveys. The section 1 staff gauge was replaced in the same location in which gauges were maintained between 1980 and 1987. However, the elevation of the new gauge can only be determined relative to positions in other years by calibration against a linear regression between lakeshore and section 1 readings available for 1984:

$$\mathrm{S1GH\ (cm)} + 100 = \mathrm{LkGH\ (cm)} + 87.04,$$

where S1GH = section 1 gauge height, and LkGH = lake gauge height ($r^2 = 0.89$; $p < 0.001$; $n = 51$).

Spawner Mortality and Recovery of Carcasses

During the six population surveys, all dead sockeye were tallied separately from live ones and pitched up onto the stream banks. The numbers pitched in each section were then summed between observers and recorded. Carcasses carrying Petersen disc tags were counted separately from untagged carcasses, and the total numbers of each color code were recorded for each stream section and the lake. Observations were made to record the dates when sockeye carcasses (a) first appeared on the spawning grounds, and (b) were most abundant. Additionally, all carcasses that had been damaged by bears were counted and the heads collected and stored in sealed, plastic bags so that morphometric measurements could be made later in the laboratory.

Tagging Procedures Used for Marking Henderson Lake Sockeye

Prior to visual surveys, large samples of adult sockeye were marked with uniquely-colored Petersen disc tags at different times during the spawning season in order to estimate escapements by the Petersen mark-recapture method (Ricker 1975) and by techniques based upon estimates of mean residence time of sockeye on the spawning grounds (i.e., stream life, sensu Bocking et al. 1988). Methods used in 1988 were consistent with those employed since 1980 at Henderson Lake when 500 - 1 500 sockeye were tagged annually at roughly weekly intervals between the third weeks of September and October (authors' unpublished data).

Sockeye were captured for tagging at a number of locations along the lowermost 100 - 150 m of Clemens Creek (Fig. 2). Fish were collected by using a 50-m X 4-m beach seine containing meshes of 7-cm aperture. The mesh size selected enabled both adult and jack sockeye to be captured efficiently. The net was deployed from a small inflatable boat equipped with a 9.9-horsepower outboard motor. Fish were then caught by closing the seine against the shore of the stream.

Each fish appearing in healthy condition was removed from the partially-submerged net by hand, held in a vee-shaped, wooden trough (fastened onto the top of a work table) while tags were applied, and then released back into the stream outside of the net. One disc tag was applied to both sides of each individual immediately below the anterior portion of the dorsal fin. Tags were fastened in place with nickel wire (7.5 cm long) inserted through both the tags and dorsal musculature of the fish. Tagged fish were secondarily marked by piercing an operculum with a standard paper punch in order to identify any loss of tags among marked sockeye.

Before each sockeye was released, its sex was determined by examining its external morphological characteristics. The numbers of each sex tagged were tallied with hand-held counters. All tagged fish recaptured by subsequent seining were also enumerated as were all other salmonid species caught incidentally.

A total of 2 443 plastic disc tags were applied during the first three trips to the spawning grounds (Table 1). Tags used in 1988 were 19 mm in diameter and either single-colored (e.g., orange) or bicolored (e.g., one-half red plus one-half white). Forty-one percent of all tags used were single-colored: 59 % were bicolored. Tagging was begun on 1 October when 505 orange tags were applied. This application was followed on 7 October by marking fish with an additional

631 green/yellow, 30 clear, and 183 red/white tags (Σ = 844). Finally, 588 red/green, 485 light blue, and 21 dark blue tags were applied on 20 October (Σ = 1 094).

Estimates of Sockeye Residence Time on the Spawning Grounds

The average residence time of adult sockeye on the Henderson Lake and Clemens Creek spawning grounds was determined using three techniques. First, mean residence time was calculated by determining the number of days between the two dates when the maximum numbers of live spawners and carcasses were enumerated respectively. The two other techniques, respectively termed (i) the cumulative tag-day method (see Bocking et al. 1988) and (ii) the tag-depletion method, were based upon counts of live, tagged sockeye made in each population survey during the spawning season.

(i) Cumulative Tag-Day Method

Spawner residence time was determined for all tags (except clear ones) applied in each of the three tagging sessions from the following relationship:

residence time = (Σ tag-days / no. tags applied).

Total tag-days were determined for each tag group by integrating the area under a tag abundance curve plotted from the numbers of tagged, live fish enumerated during visual surveys. The first point on each curve (day 0) was the total number of tags applied. Areas under the curve (AUC) were determined separately for the interval (days) between the date of tagging and the first tag-recovery date and subsequently for each interval between sequential surveys. The resulting number of tag-days was summed over all intervals. Mean residence time (days) for each tag group was then calculated by dividing this sum by the total number of tags initially applied (see Ames 1984, Bocking et al. 1988). The population mean was then calculated by averaging the residence times determined for the three sets of tags applied throughout the marking period on 1, 7, and 20 October respectively. Clear tags (applied on 20 October), which are undetectable on live fish, were excluded from all residence-time determinations.

(ii) Tag-Depletion Method

The linear equation y = ax + b was used to describe the seasonal decrease of the size of the spawning population. The natural logarithm of the numbers of tagged sockeye observed alive in four recovery periods was plotted against the number of days elapsed between the tagging and recovery dates for each color code or color group of tags. The equation of the line was then written as

$$\ln(\text{Tags}+1) = a(\text{DE}) + b \ ,$$

where a = the slope of the line, b = the y-axis intercept, and DE = the number of days elapsed between tagging and recovery dates. One was added to the observed tag number to avoid zero values for tags in the term ln(Tags). From this relationship, the elapsed time required to reach 50 % tag loss ($E_{TL}50$) was calculated and considered to be an estimate of spawner residence time.

Separate $E_{TL}50$ values were determined for the three sets of tags applied on 1, 7, and 20 October respectively. Additionally, two types of relationships were studied. In one procedure, the number of tags applied to the fish was used as a tag-recovery observation for the first day after tagging (day 1). All sockeye tagged were assumed to remain alive on the day following tag application. The y-axis intercept of the regression line for each tag group was thus constrained by the true number of tags applied at the start of the study.

Alternatively, $E_{TL}50$ values were determined from plots where the y-axis intercept was not constrained by the true number of tags originally applied. The first tag-recovery observation for the respective tag groups depended upon the timing of the first post-tagging visual surveys. This procedure allowed estimates to be made of the initial number of tags employed for each color group (E_{TS}) by extrapolating the regression line back to day 0. The accuracy of the E_{TS} estimates, and thus of the unconstrained relationships, could then be evaluated by comparison with the true numbers of tags applied.

Mean spawner residence time was averaged over all color groups for both unconstrained and constrained depletion curves. Estimates of residence time were compared and evaluated between these two models, and among the methods respectively employing tag-depletion curves, cumulative tag-day data, and the interval between peak counts of live and dead sockeye.

Population Numbers Estimated From Simple Visual Counts, and From a Spawner Abundance Curve Plus Mean Residence Time

(i) Peak Count of Live-Plus-Dead Spawners

One estimate of the sockeye spawning escapement to Henderson Lake was derived by summing visual counts of both live and dead spawners. The seasonal population estimate was taken as the maximum sum of live-plus-dead fish derived from one of the six population surveys made in 1988.

(ii) Spawner Abundance Curve Plus Mean Spawner Residence Time

A spawner abundance curve (Ames 1984, Bocking et al. 1988) was constructed by plotting the combined numbers of sockeye observed in Clemens Creek and Henderson Lake against time (days) spanning the estimated first day when fish entered the spawning grounds to the estimated last date when live sockeye were present. The area under the curve (total fish-days) was divided by the mean spawner residence time to yield the estimated total escapement (Ames 1984).

Petersen Mark-Recapture Estimates

Petersen mark-recapture estimates of sockeye spawning throughout the Henderson Lake system were derived by: (a) leaving sufficient time (one week or longer) for tagged and released fish to mix throughout the population; (b) surveying the lake and stream at subsequent intervals to count the total numbers of live and dead fish of each tag color plus the numbers of untagged live and dead sockeye; (c) removing all dead fish from the stream before the next survey; and (d) computing the total population from the observed ratios of marked-to-unmarked fish employing formulae detailed by Ricker (1975) and Seber (1982).

Both simple and stratified Petersen estimates were made of the spawning population. To estimate the population (N) by the simple Petersen method, the total number of tagged sockeye summed over all tagging periods was substituted for M; the total number of live or dead sockeye observed in subsequent visual surveys was substituted for C; and, the total number in sample C consisting of tagged individuals (all color codes combined) was substituted for R in the formula

$$N = \frac{M \times C}{R},$$

where, M = the first sample of sockeye taken from population N, marked, then released back into N;
C = the second sample of sockeye consisting of the total numbers of either live or dead spawners visually surveyed and called the "captures"; and,
R = the numbers of sockeye bearing tags in the second sample and termed the "recaptures" (Ricker 1975, Seber 1982).

The upper and lower 95 % confidence limits for the estimate were found by substituting the observed number of recaptures (R) for the unknown term (x) in the formula

$$x + 1.92 \pm 1.96 \, (x + 1.0)^{1/2},$$

and then substituting the results into $N = (M \times C) / R$ (Ricker 1975).

An unbiased estimate of the total population is obtained by the Petersen method if either one of the samples marked or recovered is random (Ricker 1975). However, the estimate may be biased if both the original marking and the recovery samples are selective. To accommodate for potential bias, stratified Petersen estimates were first adopted for Henderson Lake escapement studies in 1986 and 1987 in which sets of uniquely colored tags were applied in marking periods (strata) denoted by i and recovered in periods denoted by j. The stratified technique is used to determine the total population accurately whenever the successive "strata" marked and released maintain their separate identities due to incomplete mixing of marks among all spawners: each stratum can be treated as a separate population (Ricker 1975).

Sockeye marked in the three tagging sessions on 1, 7, and 20 October represented three color-coded strata denoted by M_i. Tagged live or dead sockeye enumerated during the four recovery surveys of 18 and 29 October, and 14 and 28 November, were denoted by R_i for each color code (or a group of codes applied in each tagging session). The total number of tagged live or dead sockeye counted during each recovery period was denoted by R_j, while the total recoveries for each period (tagged plus untagged fish) were denoted by C_j. The total population was then determined by the stratified Petersen method by substituting these values into the formula

$$N = \Sigma N_{ij} = \Sigma \left\{ R_{ij} \times \frac{M_i}{R_i} \times \frac{C_j}{R_j} \right\}$$

in which, C_j = the number of fish caught (or tallied) in the

jth period of recovery (ΣC_j is the total no. examined = C);

R_{ij} = the number of fish marked in the ith marking period which are recaptured (tallied) in the jth recovery period;

R_i = the total recaptures of fish in the ith period; and,

R_j = the total number of recaptures during the jth period (Ricker 1975).

Population estimates were made separately for live and dead sockeye. Although fish were distinguished by sex upon tagging, recovered dead sockeye both tagged and untagged were not similarly identified in 1988 due to the need to complete all counts as rapidly as possible. Confidence limits for stratified Petersen estimates were calculated by methods similar to those used for simple Petersen estimates (Ricker 1975, Seber 1982).

Escapement Samples

One hundred adult sockeye were collected on 30 Sep - 1 Oct and 75 on 22 October to determine the biological characteristics of the Henderson Lake spawning population in 1988. Sockeye were seined from the lowermost 150 m of Clemens Creek. Fish were withdrawn from the net by hand without conscious selection or rejection of individual sockeye.

Age, postorbital-hypural lengths (mm), and sex were determined for each fish by methods detailed by Steer et al. (1988). Both scales and otoliths were taken to age the fish. Lengths and sex were determined in the field; however, scale and otolith samples were transported to the laboratory at the Pacific Biological Station, Nanaimo, BC where ages were determined. Fish age was usually reconciled for each individual from otoliths and acetate impressions of scales (see Clutter and Whitesel 1956). In cases where scales were resorbed, age was determined solely from otoliths. Age is denoted using the European system: the first and second digits correspond to the number of winters an individual spent in freshwater and seawater respectively.

The age, sex, and size compositions of the spawning population were determined from the escapement samples. Age frequencies were also compared to means determined from data collected annually since 1980 for Henderson Lake sockeye escapements and those fish of this stock caught in the commercial net fishery.

RESULTS

Population Estimates

Migration Onto the Spawning Grounds, Spawning Activity, and Visual Counts of Live Sockeye

(i) Main Surveys and Total-Section Counts

Sockeye were observed spawning in Clemens Creek on 30 September during the first trip to Henderson Lake (Fig. 3). They were then distributed throughout the lower five sections of Clemens Creek and along the lakeshore adjacent to the creek (Table 2). Sockeye were using the lower six sections by 6 October, and spawners had migrated upstream to section 7 by 29 October. Maximum numbers of sockeye were counted in sections 5 and 6 during the surveys of 18 and 29 October. Because the high numbers occurring within these sections were similar between the two surveys, maximum spawner abundance and spawning activity were concluded to have occurred during the last 7 - 10 days in October. Peak sockeye numbers were estimated on 30 October (Fig. 3). The spawner abundance curve was extended to zero from the peak count and numbers of fish observed in the first three visual surveys. From this extrapolation, sockeye were concluded to have arrived at the Henderson Lake spawning grounds and in Clemens Creek around 15 September (see Fig. 3). Spawning was last observed on 17 November. No spawning was observed among the 118 sockeye counted on the last trip of 28 November. The final date of spawning was thus interpolated to 23 November.

The total count of live sockeye increased from 6 248 enumerated during the first survey of the season (29 September) to a maximum of 18 925 estimated on the survey of 29 October (Table 2). Numbers then declined rapidly to only 118 by 28 - 30 November (Table 2). Freshets limited counts to sections 5 - 7 during the survey of 29 October when peak numbers of spawners were apparently present (see Fig. 4; Appendix Table A-1). However, sockeye numbers in sections 5 and 6 combined were within eight percent of those observed in the same two reaches during the previous census of 18 October. Therefore, the total number of sockeye alive on the spawning grounds during the 29 October survey was estimated by using the ratio between counts made in sections 5 and 6 on the two consecutive trips to extrapolate numbers for sections not censused.

(ii) Strip Counts Versus Total-Section Counts

Linear regression analysis based upon counts made in six stream sections demonstrated that total-section counts and estimates generated from expansions of strip counts were highly correlated in 1988 ($r^2 = 0.86$; $p < 0.05$; $n = 6$) and were related by the equation

Total Count = 0.714(Strip Count) + 484.87 .

Comparisons made between total-section and strip counts showed that the two techniques produced total-population estimates that agreed within about seven percent for live spawners and within nine percent if both live and dead sockeye are included in the strip counts (Appendix Tables A-2, A-3, and A-4).

The strip counting method required six hours to pace the 33.5-m distances between 201 counting stations and then enumerate all sockeye at each station throughout survey sections 1 - 6 of Clemens Creek in 1988 (Appendix Table A-3). Similarly, 6.5 h were needed under ideal stream conditions to pace distances about 40-m long and count fish at 149 stations in 1984 within the same study sections (authors' unpublished data). Two days are generally required to complete total-section surveys which include both section 7 and the lakeshore. If permanent strip-count stations were marked along the stream, the strip counting method combined with a census of fish spawning in the lake might optimally realize a 50 % saving in survey time (5 - 6 h) compared with the total-section method. A time saving of > 25 % (about 2 - 3 h) would likely be realized even if permanent counting stations were not established.

(iii) Counts of Other Salmon Species

Small numbers of coho, chum, and pink salmon were observed in Clemens Creek during the visual surveys, but their numbers could not be estimated accurately. Chum salmon spawn mainly in the lowermost kilometer of Clemens Creek. Approximately 100 chum were counted in this reach on 30 October. On each of three surveys made prior to that date, 10 - 15 chum were netted each day in the same reach of stream when sockeye were collected for tagging. Two pink salmon had also been netted in section 1 during each of the first two tagging operations (1 and 7 October). Additionally, about 20 coho were counted in the uppermost survey sections (5 - 7) on 30 October. Prior to that date, two coho were observed in section 3 and three in the uppermost part of section 5 on each

visual survey. Finally, between 4 - 12 coho were found among the seine catches made in section 1 during the three sockeye-tagging trips. No coho were observed in Clemens Creek after the survey of 29 October. The low numbers of salmon in Clemens Creek other than sockeye demonstrated that population estimates of sockeye spawners were not biased due to taxonomic misidentifications associated with the presence of other species.

Physical Conditions in the Lake and Stream

Streamflows and lake levels were relatively low and stable between 29 September and 29 October as indicated by staff gauge readings at the lakeshore and in the lowest section of Clemens Creek (Fig. 4; Appendix Table A-1). Readings at the lakeshore then averaged 0.56 m and ranged between 0.33 and 0.80 m. Only six readings were available for section 1 of the stream during the same period in 1988: stream levels then averaged 0.20 m and ranged between 0.15 and 0.28 m (Appendix Table A-1). However, stream levels were calculated daily for each survey from regressions available between lake gauge and section 1 readings for 1984. These 1984 equivalent readings for Clemens Creek averaged 0.36 m and varied between 0.15 and 0.55 m prior to the late-October freshets (Fig. 4; Appendix Table A-1). Good viewing conditions were associated with the range of streamflows encountered on all population surveys made during this period.

Peak freshet conditions associated with high rainfall occurred between 30 October and 8 November. Average staff gauge readings at the lakeshore approximately doubled over those of the previous period, peaked at 1.80 m on 1 November, and remained high at 1.58 m on 8 November. The staff gauge reading in the creek on 31 October was 1.25 m, and represented a six-fold increase over that observed earlier. Water levels continued to rise, and peaked at a gauge reading of 1.50 m on 8 November. Floodwater had washed the gauge away by 14 November.

High discharges during the peak of spawning precluded accurate population estimates to be made by Petersen mark-recapture methods using carcass recoveries, and prevented the completion of the visual survey for the trip of 29 October. However, good viewing conditions were available for spawner counts in sections 5 - 7 on 30 October before water levels and turbidity peaked later in the survey. Reliable counts are thus available for those stream sections.

Stream levels remained relatively high for the final two surveys of the season (Fig. 4, T6 and T7; Appendix Table

A-1); however, viewing conditions were good. Therefore, reliable spawner counts were made despite section 1 gauge readings (1984 equivalents) which varied between 0.56 and 0.76 m on actual survey dates. The high turbidity associated with freshets during the 29 October survey was reduced later in the season and thus did not hinder visual enumerations.

Spawner Mortality and Recovery of Carcasses

Dead sockeye were observed and pitched from the stream from 18 October to the end of the season. The fewest dead fish were counted and pitched between 29 October and 1 November when high stream discharge washed many carcasses out of Clemens Creek: only 128 dead sockeye were found during that survey (Table 3). However, carcass recoveries were limited to sections 5, 6, and 7 due to freshet conditions. Numbers were extrapolated for unsurveyed reaches from the ratio of carcasses pitched from sections 5 plus 6 between the studies of 18 and 29 October (Table 3).

Two weeks later, 2 085 carcasses were observed and pitched from the stream when flows had decreased and visual surveys could be resumed (Table 3). The numbers of carcasses found then fell to 688 on the final survey of the season (28 November; Table 3).

A total of 3 106 sockeye carcasses were recovered during 1988: few of these were apparently killed by bears. However, freshets probably washed away many bear-killed carcasses during the peak of spawning activity. Bear-damaged carcasses were observed over the entire length of Clemens Creek although only one bear was seen on one date. However, records are available only for 30 October when 20 bear-damaged carcasses were observed along the length of the stream (mainly in sections 5 and 6). In sections 5 - 7, < 10 live sockeye were seen to have scars obviously from bear attacks. Of the 20 bear-damaged carcasses, it was difficult in many cases to determine whether bears had caught live fish or had fed upon dead salmon.

Visual Counts and Recoveries of Tagged Sockeye

(i) Live Spawners

A total of 424 live sockeye bearing tags were enumerated among the four recovery periods spanning 18 Oct - 30 Nov. Fewer tagged, live sockeye were counted on each

successive stream survey as mortality increased in the spawning population (Table 4): only one tagged live fish was observed on the last tag-recovery date of 29 November. Although only 112 tagged fish were observed on the survey of 29 October, only sections 5 - 7 were covered (Table 4). Numbers were expanded to account for unsurveyed sections by determining percentages of tagged salmon observed in all study sections during (i) the previous survey of 18 October for orange, green/yellow, and red/white tags (applied early in the season between 1 and 7 October) and (ii) the following survey of 14 November for red/green, light blue, and dark blue tags (applied later in the season on 20 October). Observations for 14 - 17 November were used for the last set of applied tags because only two tags of that group were observed on the earlier survey of 18 October (Table 4). Extrapolating these percentages to the unsurveyed reaches, 544 tagged sockeye might have been observed throughout the system during the trip of 29 October had a complete census been possible (Table 5).

The observed numbers of live spawners bearing tags were low in 1988 (Table 4). Including extrapolations for the survey of 29 October, only 1.1, 2.9, 3.8, and 0.8 % of the total numbers of sockeye observed respectively on the four consecutive recovery periods carried tags. Additionally, about 3.0 % of live sockeye enumerated during strip-counting procedures on 25 October were tagged (see Table 5).

The surface area of the tags used in 1988 was about 42 % less than that of the large-diameter (25-mm) tags employed in all previous years. Comparisons of the numbers of tagged, live fish counted in 1987 and 1988 suggest that the small-diameter (19-mm) tags were not as readily detected as the larger discs. On each tag recovery date, the percentage of applied tags detected was much higher for the large tags used in 1987 (Table 5). On average, the large tags were 2.84-times more detectable (Student's t, $p < 0.05$). The numbers of tags applied, and the elapsed time between each period of tag application and visual enumeration, were roughly comparable between years (Table 5). Similarly, stream and lake conditions for visual counting were comparable between 1987 and 1988 (authors' unpublished data). Given that tag numbers, tagging frequency, survey schedules, viewing conditions, and sockeye residence times were similar between years, the mean percentage of applied tags observed in each year provides a measure of visual detection efficiency for each tag type.

(ii) Sockeye Carcasses

Only 97 of 3 106 carcasses (3.1 %) recovered throughout the season were tagged (Table 6). The percentage

of carcasses carrying tags was initially high, varying from 10.2 to 7.0 % on the surveys of 18 and 29 October respectively. However, these proportions fell markedly after high discharges in Clemens Creek occurred during the peak of spawning activity between the last week of October and the first week of November. Only 2.8 and 1.3 % of all carcasses pitched during the surveys of 14 and 28 November respectively carried tags. Freshets had displaced large numbers of both tagged and untagged dead sockeye downstream into the lower sections of Clemens Creek and into Henderson Lake. Although many tagged fish were then removed from the stream, the low ratios of tagged-to-untagged carcasses observed late in the season indicated that large numbers of new sockeye migrants had entered Clemens Creek after the last tagging date (20 October) and thus remained untagged.

With one exception, all sockeye carcasses (97) secondarily marked with opercular holes still carried their plastic discs. One head containing an opercular hole was recovered without its body: no observation of tag loss was thus possible for that individual. Despite this exception, all observations indicated that tag loss rates were zero for all color codes. Therefore, loss of tags did not affect the ratios of tagged-to-untagged sockeye observed throughout the season or Petersen mark-recapture estimates which depend upon tag recoveries.

(iii) Distributions of Tagged Spawners

Not only were large numbers of sockeye carcasses displaced downstream by mid-season floods, the ratios of tagged-to-untagged carcasses also diverged markedly between stream sections after the freshet period. Sixty-nine percent (40) of 58 tagged carcasses recovered during the survey of 14 November were located in section 1 alone (Table 6). By comparison, only 48 % of the total number of carcasses pitched were found in that section (Table 3). Nearly 48 % of all carcasses (990 of 2 085 sockeye) were also recovered several kilometers upstream in sections 4 and 5 (Table 3).

The distributions of tagged carcasses diverged further from untagged ones during the final survey of 28 November. Eight tagged carcasses from a total of only nine recovered (about 89 %) were found downstream in section 1 (Table 6). By contrast, only about 38 % of the total number pitched (267 of 688 fish) were found in that area whereas about 43 % were located in sections 4 and 5 (Table 3).

Overall, nearly 72 % of the 67 tagged carcasses recovered from the stream during the two post-freshet surveys

were counted in section 1 (Table 6). By comparison, only about 46 % of the total number of carcasses recovered on the same days were found in that location while another 46 % were recovered upstream in sections 4 and 5 (Table 3). About 89 % of 3 106 carcasses pitched seasonally were encountered during the last two surveys when the recoveries of tagged individuals was clearly non-random and biased strongly toward section 1.

The distribution of live sockeye bearing tags also changed after the freshets of 29 Oct - 1 Nov. Before the freshets, tagged fish were almost evenly mixed throughout most of the sockeye population in Clemens Creek except for those in section 1. Without adjusting observed numbers upward to compensate for low tag-detection efficiencies (Table 5), between 2.2 and 2.4 % of all sockeye counted in sections 3 - 6 carried tags during the survey of 18 October. These four sections held nearly 47 % of the 17 346 sockeye enumerated during that trip. On the other hand, < 0.02 % of the 5 700 fish counted in section 1 were tagged. However, this observation likely reflects the rapid migration of (i) tagged spawners into upstream sections prior to the peak of spawning activity, and (ii) untagged sockeye into section 1 from the lake.

After the 30 October freshet, 74 % of 121 live, tagged sockeye counted during the survey of 14 November were found in section 4 (Table 4). Although this section at the same time contained only 40.5 % of the total numbers of sockeye still alive in the system, it was then the most heavily populated reach of the stream and contained over twice as many fish as any other section (Table 2). About 6.8 % of all sockeye observed in section 4 carried tags. Over 20 % of live spawners were distributed upstream in sections 5 and 6 while > 18 % of the population remained in section 1 (Table 2). Tagged fish were almost evenly mixed among these reaches and comprised between 2.1 and 2.3 % of all sockeye counted in each. These post-freshet observations together demonstrate that (i) tagged, live sockeye were well mixed throughout the spawning population in Clemens Creek, and (ii) their distribution was not seriously biased toward section 4 despite the large number of tagged fish observed there late in the season.

The statistical validity of Petersen mark-recapture estimates depend partly upon the random distribution of recovered tags (Ricker 1975). Such estimates thus become questionable when biased (non-random) tag recoveries occur. Although the distribution of tagged carcasses was clearly biased toward section 1, live fish bearing tags appeared to be well mixed throughout most parts of the spawning grounds.

Estimates of Sockeye Residence Time on the Spawning Grounds

(i) Time Interval Between Peak Counts of Live and Dead Sockeye

The greatest number of live sockeye was observed on the spawning grounds on 30 October (Table 2). Correspondingly, the largest number of sockeye carcasses was pitched from the stream by 17 November during the fifth trip of the season (Table 3). The seasonal distributions of the numbers of both live and dead sockeye appear approximately normal, have well-defined peaks, and are not markedly tailed in any direction (Fig. 5). The 18-day period spanning the peaks representing the maximum observed numbers of live and dead spawners respectively is thus an easily derived estimate of mean residence time on the spawning grounds (Fig. 5).

(ii) Cumulative Tag-Day Method

Prior to adjusting tag recoveries to account for low visual detection efficiencies, mean spawner residence times for marked sockeye decreased seasonally from 13.0 days for early migrants tagged on 1 October to 12.3 days for those tagged on 20 October (Table 7). The residence time calculated for sockeye tagged on 7 October was only 8.8 days due to especially low visual recoveries. Seasonal reductions in spawner residence time are known to occur among salmon entering spawning grounds later in the season (Ames 1984). Fish entering earlier in the year frequently hold in pools for variable periods of time before spawning actually occurs. Those entering later tend to spawn almost immediately. Seasonally, the mean spawner residence time based upon the unadjusted cumulative tag-day method was determined to be 11.4 days.

Visual recoveries of tagged, live spawners remained low despite extrapolating tag counts for study reaches not surveyed during the trip of 29 October. Consequently, the mean residence time calculated using the unadjusted cumulative tag-day method was 36.7 % less than that determined from the interval between peak counts of live and dead sockeye. However, residence times based upon the cumulative tag-day method increased sharply when tag recoveries were adjusted upward by a factor of 2.84 to account for reduced visual detection efficiencies in 1988 (see Table 5). Seasonal mean residence time increased to 18.4 days (Table 8) and closely approximated that determined from the interval between peak counts of live and dead sockeye.

Adjustments for tag-detection efficiencies resulted in some inaccuracies. For example, the mean residence time for spawners tagged late in the season (20 October) was clearly overestimated at 22.8 days (Table 8). This high estimate was caused by the application of two separate expansions for tag recoveries on 30 October to account for unsurveyed sections as well as low tag visibility. Expanded counts generated 100 % recovery of applied tags 10 days after tagging (Table 8). Late-season mortalities were thus strongly underestimated by this projection and caused subsequent overestimates of both cumulative tag-days and residence time. The effect of this error over all tag groups was small given that the mean seasonal residence time determined from adjusted cumulative tag-day procedures differed from that determined from peak counts of live and dead spawners by only two percent. Considered seasonally, adjusted tag recoveries were thus accurate estimates of the true number of tagged fish available for counting (and thus of spawner mortality rates).

(iii) Tag-Depletion Method

Averaged over all tag groups, sockeye residence time on the Henderson Lake spawning grounds varied from 4.6 days for adjusted tag-depletion regressions unconstrained by the true numbers of applied tags, to 11.8 days for regressions where initial tag numbers were used as the first tag-recovery observation (Table 9). All tag-loss regressions but one (20 October tags, unconstrained) were highly correlated (r^2 = 0.800 - 0.998; Table 9) and statistically significant ($p < 0.001 - 0.05$); however, both types of regressions greatly underestimated mean residence time relative to alternative techniques.

The magnitude of this bias was strongly reduced by using constrained regressions. Mean residence time based on constrained curves was > 2.5-fold higher than that based upon unconstrained ones. These results show that tag-depletion curves are especially sensitive to the frequency and timing of tag-recovery surveys. When the initial number of applied tags was used as the first tag-recovery observation, not only was the tag-depletion regression strengthened by increasing the number of observations (n), but its y-axis intercept was also constrained so that the slope of the regression line was less steep compared to unconstrained curves. Therefore, tag-loss rates defined by the slope were lower, and resulting $E_{TL}50$ values were correspondingly higher.

Despite this large increase in $E_{TL}50$ estimates, constrained tag-depletion techniques underestimated sockeye residence time by about 56 % compared to that calculated from

adjusted cumulative tag-day procedures. Residence times generated from tag-depletion curves would be further biased low if they were based upon tag recoveries unadjusted for the small-sized tags used in 1988. Accordingly, residence-time estimates based upon regressions unadjusted for low tag-detection efficiencies are not presented.

The actual numbers of tags employed for each tag group were poorly estimated from unconstrained regressions. These observations illustrate the inaccuracy of this method. The E_{TS} values for tags applied on 1, 7, and 20 October were overestimated by about 8.7, 3.0, and 10.7 fold respectively (Table 9). All $E_{TL}50$ estimates subsequently based on these E_{TS} values were far lower than those derived from constrained regressions. Estimates of residence time decreased with higher projected numbers of applied tags.

Tag-depletion curves produced estimates of residence time that were clearly biased low relative to those generated by other techniques. In 1988, mean spawner residence time for Henderson Lake sockeye was best estimated from the interval between peak counts of live and dead spawners. However, the cumulative tag-day method produced nearly identical results after tag recoveries were adjusted to compensate for reduced visual detection efficiencies associated with small tags.

Population Numbers Estimated From Simple Visual Counts, and From a Spawner Abundance Curve Plus Mean Residence Time

(i) Peak Count of Live-Plus-Dead Spawners

The peak visual count of live-plus-dead spawners was estimated for the survey of 29 October when 19 634 sockeye were concluded to be on the spawning grounds (Tables 10, 11). This total consisted of 18 925 live sockeye and 709 carcasses (Table 10). Simple visual counts provide a minimum estimate of escapement (Ames 1984), especially when viewing conditions are poor due to reduced visibilities during freshets (Cousens et al. 1982, Van Hyning 1973). The present count must also be accepted as a minimum escapement estimate because: (i) simple visual enumerations do not account for either the seasonal mortality of early sockeye migrants or the continuing immigration of new fish onto the spawning grounds (that is, spawner turnover); and, (ii) peak numbers occurred during a period of high streamflows when sockeye abundance in unsurveyed sections 1 - 4 and Henderson Lake was estimated by extrapolation and when many carcasses were likely washed downstream into the lake.

(ii) Spawner Abundance Curve Plus Mean Spawner Residence Time

The area under the spawner abundance curve represented 689 430 fish-days (Fig. 4). This value divided by a mean spawner residence time of 18 days resulted in an estimated escapement of 38 302 fish. This estimate was virtually double that determined from the peak count of live-plus-dead spawners. The additional numbers estimated from the spawner abundance curve likely reflect accurately the seasonal turnover of sockeye on the Henderson Lake spawning grounds because (a) the average sockeye residence period calculated from the interval between peak counts of live and dead sockeye was consistent with residence times determined in other years (authors' unpublished data), and (b) was supported by the 18.4-day residence time derived from cumulative tag-day procedures in which visual recoveries of small tags were adjusted. The adjusted cumulative tag-day method resulted in an escapement estimate of 37 469 sockeye (Table 11).

When tag recoveries were not adjusted to account for low tag-detection efficiencies, mean residence time determined from the cumulative tag-day method was strongly biased low and caused the corresponding escapement estimate to reach 60 476 fish (Table 11). This estimate was clearly biased high and exceeded by 1.6 times that determined from the same procedure when visual tag recoveries were adjusted (Table 11).

Spawner residence times based upon adjusted tag-depletion regressions generated escapement estimates that were strongly biased high. This bias was proportional to the differences in spawner residence times estimated by the alternative tag-depletion techniques. The escapement of 58 426 sockeye estimated from constrained regressions (11.8-day residence time; Table 11) was 1.5-fold higher than that determined from the adjusted cumulative tag-day method. Had unconstrained regressions been used, the low (4.6-day) residence time derived from that procedure would have further inflated the population estimate to 149 876 fish.

Petersen Mark-Recapture Estimates

(i) Estimates Based on Counts of Live Sockeye

Simple and stratified Petersen mark-recapture estimates of sockeye escapement based on counts of live spawners were 52 972 and 52 118 fish respectively (Table 11, Appendix Table A-5). These estimates were respectively 38 and

36 % higher than that determined by using the AUC method combined with a mean spawner residence time of 18 days. Both were based upon counts of tagged sockeye (visual recoveries; Table 4) that were increased by a factor of 2.84 to compensate for low visual detection efficiencies (Table 5). Mark-recapture estimates are highly sensitive to sampling bias affecting recoveries of tagged individuals (Ricker 1975, Seber 1982). Without these upward adjustments to R or R_i, the simple and stratified Petersen estimates would have been biased upward to unacceptable levels (225 354 and 223 710 sockeye respectively).

The close correspondence between the simple and stratified Petersen estimates demonstrated that the three groups of tagged sockeye were equally well mixed throughout the spawning population. No group of tagged fish was spatially distinct from another (Table 4). Although most observations show that tagged sockeye occurred throughout the stream, the 1988 escapement was likely overestimated by Petersen mark-recapture methods because of low frequencies of tagged fish occurring in some parts of the system. For example, when escapements were rapidly approaching peak numbers during the survey of 18 October, only 0.05 % (< 0.02 % unadjusted) of 5 700 sockeye enumerated in section 1 carried tags. Section 1 contained 32.9 % of the population at that time; furthermore, no tags were reported for the estimated 3 000 spawners distributed along the lakehead beach. Therefore, sections 1 and the lake together contained > 50 % of the escapement, but only 0.03 % of these fish carried tags. Tags were observed on only 3.1 % (adjusted) of the total population during that survey. Similarly, lake spawners formed nearly 19 % of the population on 14 - 17 November, but no tagged individuals were observed among those fish.

(ii) Estimates Based on Recoveries of Sockeye Carcasses

Simple and stratified Petersen estimates of sockeye escapement based on carcass recoveries were 78 226 and 80 963 fish respectively (Table 11, Appendix Table A-6). These estimates were about double that determined from AUC methods combined with an 18-day mean residence time, and about 1.5-fold higher than Petersen estimates based on counts of live sockeye. Inflated mark-recapture estimates were due partly to the relatively small numbers of tagged carcasses recovered during the last two visual surveys: among 2 085 carcasses counted on the survey of 14 November, only 58 carried tags. Similarly, only nine tagged fish were counted from a total of 688 carcasses on the final survey (Table 6). These low recoveries suggest that a large proportion of the 1988

migration was not sampled for marking. Tags were last applied one week prior to the estimated peak of sockeye abundance; therefore, the tagging program was not able to mark representative proportions of fish entering the stream during the last week of October and the first week of November.

Additionally, high streamflows washed many sockeye carcasses downstream both into the lowest survey sections and out of the spawning grounds to the bottom of Henderson Lake during the same period in late October and early November when most of the spawning activity occurred and when spawner mortality was coincidentally high. Although the distributions of both tagged and untagged carcasses enumerated during the last two visual surveys were then biased toward the lowest survey area of Clemens Creek (section 1), a disproportionate number of tagged sockeye were recovered among the total numbers of carcasses pitched from that reach after the freshets of 29 Oct - 1 Nov. Because the recovery of tagged carcasses was thus biased strongly toward section 1, Petersen estimates based on carcass recoveries were unreliable.

Age, Length, and Sex Composition of Escapement

Of the sample of 175 sockeye collected for age, sex, and hypural-length determinations, 163 were used to characterize the 1988 Henderson Lake spawning escapement. The ages of 12 fish could not be determined unequivocally from either scales or otoliths; therefore, these individuals were not used in further analyses.

Males and females respectively formed 50.9 and 49.1 % of the final sample of 163 sockeye (Table 12). The sex composition of the escapement sample was almost identical to the 1:1 sex ratio of the 2 443 sockeye sampled for tagging (Table 1). Therefore, no evidence of bias was associated with either sockeye sample. Among male sockeye, 20.5 % were four years old (age 1.2 fish) while 79.5 % were five years old (age 1.3 fish). By contrast, 40.0 % of females were four years old, 58.8 % were five years old, and one individual (1.2 %) was six years old (age 1.4). No jack sockeye (age 1.1 fish) occurred in the sample.

Combining males and females, 30.1 % of the sample consisted of four-year-olds, 69.3 % were five years old, and only 0.6 % were six years old (Table 12). Nearly two-thirds of the four-year-old fish were females (65.3 %) while only 34.7 % were males. These proportions were reversed among five-year-old sockeye: only 41.6 % were females, while 58.4 % were males.

The mean postorbital-hypural lengths of males and females were statistically equal within sockeye age groups (Fig. 6; Table 13; two-sample t-tests, all $p > 0.05$). Four-year-old males and females were respectively 442.3 and 445.1 mm long on average (Fig. 6; Table 13). Five-year-old sockeye were significantly larger than the four-year-olds (Student's t, all $p < 0.05$): on average, five-year-old males and females were respectively 503.9 and 499.3 mm long (Fig. 6; Table 13). The only six-year-old sockeye identified from the samples was a female 457 mm long.

DISCUSSION

Salmon spawning escapements determined from counts of live-plus-dead fish are biased low and should be considered minimum estimates (Atkinson 1944, Brett 1952, Cousens et al. 1982, French and Wahle 1960). Ames (1984) demonstrated that peak visual counts are not reliable indicators of the total abundance of spawners. For example, he showed that peak live counts alone underestimated true escapement numbers of chum salmon by 27.3 - 72.7 % in a stream tributary to Puget Sound in Washington State. This wide range of percentages suggested that his peak counts were characterized by both low precision and low accuracy. Similarly, Brett (1952) observed that visual counts of sockeye in the Skeena River were about one-third the numbers determined at a counting weir. Any factor such as deep water, rainfall, or turbidity that reduces visibility will cause simple visual counts to underestimate true escapements (Ames 1984, Cousens et al. 1982, Van Hyning 1973). Because temporal changes in these controlling factors can occur both within and between seasons, simple visual counts are often susceptible to poor precision as well as low accuracy.

The peak count of 19 634 live-plus-dead sockeye provided the lowest estimate of sockeye escapement to Henderson Lake in 1988. This estimate is undoubtedly biased low relative to both the true seasonal escapement and to the true numbers present during the peak of spawning. Peak sockeye abundance occurred during a period of high streamflows when visual surveys could not be made in either sections 1 - 4 or Henderson Lake, and when many carcasses in surveyed reaches were likely washed downstream. Sockeye numbers in unsurveyed areas could only be estimated by extrapolating population proportions occurring in the same sites in the previous survey and thus are difficult to corroborate unequivocally.

Any method that accounts for temporal spawner mortality and immigration onto the spawning grounds (turnover) is preferable to simple visual counts and will increase population estimates relative to those determined from a single count of peak numbers (Ames 1984). The estimated escapement of 38 302 sockeye determined from a spawner abundance curve combined with mean sockeye residence time of 18 days is thus concluded to be more accurate than that available from the peak count of live-plus-dead sockeye given the general disadvantages of simple visual counts and the freshet-associated limitations of the peak count made on 30 October.

Salmon escapements can be estimated with acceptable accuracy from spawner abundance curves combined with data on stream residence times when (a) surveys are conducted in small streams when visibility is good, (b) the entire spawning area can be censused, and (c) counts throughout the spawning season are scheduled at intervals no longer than the true residence time of the spawners (Ames 1984, Cousens et al. 1982). These criteria were satisfied for the 1988 sockeye escapement study except during the freshet-shortened survey of 29 October.

The seasonal frequency of visual surveys, and the timing of the first survey following the application of tags to the fish, rely critically upon prior knowledge of spawner residence time. Variations in residence time should be determined from analyses of visual enumerations conducted in the same system in previous years. Eight years of observations have revealed that the residence time of sockeye entering Clemens Creek early in the spawning season is usually about 20 days (authors' unpublished data). Accordingly, tag-recovery data were first collected in the present study 19 days after tags were first applied on 1 October. Subsequent surveys were made more frequently so that (i) the number of sockeye present during the peak of population abundance and spawning activity could be enumerated accurately, and (ii) reductions in spawner residence time known to occur among salmon entering the stream later in the season could be determined (Ames 1984).

Cousens et al. (1982) speculated that under ideal survey conditions, spawner abundance curves can approximate weir counts within 10 - 15 %; however, rigorous studies demonstrating such relationships are presently unavailable. Population assessments employing spawner abundance curves also have potential disadvantages. These estimates depend critically upon accurate determinations of mean spawner residence times. The results of this study have shown that residence times based upon (i) the interval between peak counts of live and dead sockeye, (ii) the cumulative tag-day method, and (iii) tag-depletion curves are differently

sensitive to factors affecting counting efficiency and to the frequency and timing of visual surveys.

Reduced counting efficiency due to consistently poor viewing conditions throughout a season should have little effect on residence time determined from the interval between maximum counts of live and dead spawners: the peak abundance of either live or dead fish should be identifiable from relative numbers generated from sequential surveys. The determination of the interval between peak counts is relatively unaffected by usual variations in visibility and streamflow unless the period of maximum spawner abundance is prolonged. If the abundance of live spawners remains high during consecutive surveys, and accurate counts are impossible due to poor visibility, the true peak in population numbers will be difficult to identify and will be only roughly approximated at best. Additionally, prolonged freshets during the period of maximum spawner mortality can remove carcasses from the spawning grounds and prevent the temporal identification of peak numbers.

Determination of the interval between peak counts of live and dead spawners depends crucially upon the schedule of visual surveys. Should maximum abundances occur only briefly, these temporally abrupt peaks might be missed even if surveys are conducted at intervals of 7 - 10 days. The assignment of spawner residence time again becomes arbitrary, approximate, and fixed to actual survey dates. The estimate will be accurate only if the survey schedule coincides closely with the occurrence of peak numbers of live and dead salmon. Given these disadvantages, the interval between peak counts should not be used alone to estimate mean spawner residence time.

The cumulative tag-day and tag-depletion methods provide alternate and potentially more accurate ways of calculating residence time but also are highly sensitive to counting efficiency and the frequency and timing of spawner surveys. Should suboptimal viewing conditions reduce the numbers of live fish carrying tags that can be counted, tag-loss (mortality) rates will be overestimated by both methods, calculated mean residence time will consequently be biased low, and the resulting population estimate might be substantially higher than the true number of spawners (see Ames 1984, Neilsen and Geen 1981). Given that stream visibilities are rarely ideal such that all live, tagged spawners can be enumerated in each survey, salmon escapements estimated using spawner abundance curves and mean residence time might generally exceed true population numbers unless weighting factors accounting for reductions in tag visibility are available. For example, cumulative tag-day data unadjusted for low tag-detection efficiencies generated an escapement estimate 61 % higher than that determined by the

same method when visual tag recoveries were adjusted (Table 11).

Under the same conditions of tag visibility, residence times determined from tag-depletion regressions always remained low compared to those determined from the cumulative tag-day method. However, correlation coefficients (and r^2 values) of tag-depletion regressions generally increased, and the tendency to underestimate residence times was reduced, when the true numbers of tags originally applied to the fish were included as observations. This inclusion both increased the frequency of surveys (observations = n) and constrained the y-axis intercept of the regression line. Therefore, to improve the accuracy of estimates made by employing this technique, tag-recovery observations should be made shortly (e.g., one day) after tagging. These observations would also help provide an index of tag-detection efficiency to quantify and reduce bias resulting from suboptimal viewing conditions. The numbers of tags observed in visual surveys can be accurately adjusted according to given conditions to compensate for differences between numbers detected and true numbers present.

In the present study, no visual calibration for tag-detection efficiency was made by surveying populations shortly after tagging: all fish marked for future counting were assumed to remain alive one day later (day 1), and stream visibility was assumed to be adequate to permit the counting of all of these individuals on that day. Estimates of mean residence time derived by the tag-depletion method are thus strongly limited by these assumptions.

Observations at Clemens Creek have shown that sockeye mortality is temporally non-linear and follows a roughly sigmoidal pattern (author's unpublished data). Logarithmic transformations provide linear approximations of this mortality. Consequently, tag-depletion regressions overestimate mortality during the period immediately after tagging when most sockeye are alive, and underestimate mortality in subsequent periods. The overall effect is that tag-depletion techniques will consistently underestimate spawner residence time. The magnitude of the bias characteristic of tag-depletion techniques can be quantified relative to other methods of estimating residence time by employing all methods simultaneously.

This investigation has shown clearly that survey schedules and visual counting efficiencies must be established carefully in order to estimate populations from residence-time techniques combined with spawner abundance curves. Estimates derived from these methods are often difficult to use alone as absolute assessments of spawner abundance, and should be used

cautiously as indices of true escapements whenever counting efficiencies are unknown and when the frequency and timing of visual surveys are suspected to result in sampling bias.

Among the three methods employed to estimate mean sockeye residence time in 1988, the interval between peak counts of live and dead sockeye and the adjusted cumulative tag-day method violated the fewest assumptions. Spawner residence times and corresponding population estimates agreed closely between the two techniques. Tag-depletion regressions might also provide acceptable estimates of residence time and population abundance if inherent biases can be quantified and calibrated against other methods.

Low recoveries and biased distributions of marked individuals frequently cause Petersen mark-recapture studies to overestimate true population numbers (Simpson 1984, Ricker 1975). For example, Brett (1952) found that Petersen estimates of sockeye in the Skeena River were about twice that determined from weir counts. Simpson (1984) reported that mark-recapture estimates of sockeye escapements to several British Columbia streams exceeded weir counts by 21 % on average. Low recoveries of tagged carcasses in 1988 clearly resulted in greatly inflated Petersen mark-recapture estimates based upon counts of dead sockeye on the Henderson Lake spawning grounds. Tags were observed on only 2.4 % of carcasses recovered during the two main recovery periods (14 and 28 November). Additionally, the recovery of tagged carcasses was strongly biased toward the lowest section of Clemens Creek after strong mid-season freshets. Escapements of 78 226 and 80 963 sockeye estimated respectively from simple and stratified Petersen mark-recapture techniques were undoubtedly biased high.

Petersen techniques based upon counts of live sockeye also overestimated escapements because low numbers of marked fish (0.03 %) were observed in the lowest reach of Clemens Creek and the lake when these sites together contained > 50 % of the sockeye population near the peak of spawning activity. However, all tag groups were well represented in most other parts of the spawning grounds throughout the main part of the spawning season. Therefore, the simple and stratified Petersen estimates of 52 972 and 52 118 sockeye respectively are useful indices of the true numbers escaping to Henderson Lake in 1988. The present estimates exceeded those derived using some of the alternate techniques; however, they are directly comparable to Petersen estimates made in previous years despite the use of small-sized tags. Low detection efficiencies associated with these tags were accounted for by calibrating 1988 tag recoveries against those made for large tags in 1987.

All escapement estimates were limited in 1988 by the need to extrapolate counts for unsurveyed reaches during the peak of spawner abundance. All estimates, except those based upon the peak count of live-plus-dead spawners and mark-recapture data for carcasses, further required adjustments to the numbers of tagged sockeye recovered due to poor detection efficiencies associated with the use of small-sized tags. Despite these requirements, the spawner abundance curve combined with either the interval between peak counts of live and dead sockeye or the adjusted cumulative tag-day method provided reasonable estimates of sockeye escapement to Henderson Lake. Both methods were associated with fewer assumptions and limitations than alternate procedures in 1988. In contrast with mark-recapture methods, neither technique required that tagged fish be well mixed throughout the spawning population. The population estimate generated by the adjusted cumulative tag-day method was probably biased slightly low because multiple data expansions caused tag recoveries (and thus residence times) to be overestimated in late October. The estimate of 38 302 sockeye based upon the interval between peak counts of live and dead sockeye thus appears to have approximated the true escapement most closely.

Some modifications to the annual escapement enumeration and sampling programs for Henderson Lake sockeye might be implemented based upon present results. Freshets affected all population estimates adversely by preventing complete visual enumerations during the period when the maximum number of spawners were present in both Clemens Creek and the lake. Total-section counts may require two days or more when populations are large and when stream discharges are increasing rapidly. A more rapid counting technique under such conditions is required so that surveys of the entire stream can be completed before discharge increases to the point that visual observations become impossible. Observers using the strip counting method required only one day to complete a census of six sections of Clemens Creek and produced population estimates within seven percent of those derived from total-section counts. This relatively rapid method can be employed in the future as an alternate enumeration technique when rapidly increasing streamflows do not permit total-section counts. The time required to complete each survey might potentially be reduced by 50 % or more if permanent strip-count stations were established.

Petersen mark-recapture estimates and spawner residence times based upon tag recoveries for live fish would be more accurate if tags were easy to see and readily identifiable by observers in the field. Therefore, Petersen disc tags must be highly visible, especially when high streamflows and associated turbidity reduce counting efficiency. Large, single-colored tags appear to be easier to

distinguish unambiguously than are small, bicolored ones, particularly when one color is of relatively low visibility (e.g., dark green) or is used in more than one set of bicolored tags (e.g., yellow or red).

Visual detection efficiencies should be determined for disc tags of different colors over a wide range of viewing conditions defined by streamflow, rainfall, turbidity, and light intensity (e.g., cloud cover). The percentages of each color detected would allow: (i) the most easily observed colors to be identified and used for field studies; (ii) the numbers of tags counted in visual surveys to be adjusted according to specific viewing conditions; and, (iii) adjustments to population estimates based on tag recoveries for previous years. Additionally, the numbers of tagged fish available for counting on the spawning grounds can be determined from visual surveys conducted soon (e.g., one day) after tagging. Together with systematically determined tag-detection efficiencies, this information can be used to refine tag-recovery data for Petersen mark-recapture estimates, and improve the accuracy of mean spawner residence times generated from either the tag-depletion or cumulative tag-day methods.

This study illustrated that large variations can occur among escapement estimates generated by different methods. Therefore, the AUC estimate for Henderson Lake sockeye in 1988 is difficult to compare directly to the Petersen mark-recapture estimates available for this stock for most years spanning 1980 - 1987 (Table 14). Although the present AUC estimate exceeded mean escapements for those years by > 15 %, direct comparisons among years can best be made by employing simple Petersen estimates based upon live sockeye (Table 14). In contrast with 1988, AUC estimates for previous years were frequently biased high and exceeded Petersen estimates (authors' unpublished data). Therefore, large variations in the behavior of a given technique can also occur among years.

Sockeye escapements to Henderson Lake have rarely exceeded or approached the current target number of 50 000 between 1980 and 1988. In 1982, 56 065 sockeye were estimated to have escaped the fishery, and numbers in 1983 and 1984 reached respectively 86 and 90 % of the target. However, estimated escapements in other years have varied between only 13.5 and 75 % of the management goal. Petersen estimates for 1988 (based on live fish) exceeded this goal, and the AUC estimate was about 77 % of target numbers (Table 14). Estimates based on either method thus indicate that the number of spawners returning to Henderson Lake have recovered strongly from eight-year lows observed in 1985 and 1986. Returns for 1986 were especially low and no commercial net

fishery was then permitted: only 6 767 sockeye returned to Henderson Lake in that year (see range, Table 14).

In most years, the largest proportion of Henderson Lake sockeye escapements have consisted of five-year-olds (Table 15). Between 1980 and 1987, five-year-old sockeye made up on average 62.0 % of the spawning population (range: 23.0 - 88.4 %). The age structure of the 1988 escapement was consistent with this trend (Table 15). Combining the 1988 data with those of the previous eight years, five-year-old sockeye have formed 62.8 % of the Henderson Lake escapements on average (SD $\pm$ 21.3 %). By contrast, four-year-olds have formed on average only 34.7 % of the population. As in most other years, three-year-old jacks were absent from the Henderson Lake stock in 1988, and six-year-olds were rare (Table 15). Only in 1980 and 1987 were four-year-old fish the dominant age group, forming 52.5 and 76.0 % of escapement samples respectively.

With the exception of 1980, the age composition of escapements generally reflected that of commercial net catches between 1980 and 1988 (Table 15). The close similarity in the age composition of escapements and catches indicate that the age structure of the Henderson Lake stock returning in 1988 was described accurately from the escapement sampling program conducted on the spawning grounds.

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REFERENCES CITED

AMES, J. 1984. Puget Sound chum salmon escapement estimates using spawner abundance curve methodology. In Proceedings of the workshop on stream indexing for salmon escapement estimation. Edited by P. E. K. Symons and M. Waldichuk. Can. Tech. Rep. Fish. Aquat. Sci. 1326: pp. 133 - 148.

ATKINSON, C. E. 1944. The problem of enumerating spawning populations of sockeye salmon. Int. Pac. Salmon Fish. Comm. Annual Report 1943: 37 - 44.

BOCKING, R. C., J. R. IRVINE, K. K. ENGLISH, and M. LABELLE. 1988. Evaluation of random and indexing sampling designs for estimating coho salmon (Oncorhynchus kisutch) escapement to three Vancouver Island streams. Can. Tech. Rep. Fish. Aquat. Sci. 1639: 95 p.

BRETT, J. R. 1952. Skeena River sockeye escapement and distribution. J. Fish. Res. Board Can. 8: 453 - 468.

COUSENS, N. B. F., G. A. THOMAS, C. G. SWANN, and M. C. HEALEY. 1982. A review of salmon escapement estimation techniques. Can. Tech. Rep. Fish. Aquat. Sci. 1108: 122 p.

CLUTTER, R. I. and L. E. WHITESEL. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bull. 9: 159 p.

FRENCH, R. R. and R. J. WAHLE. 1960. Salmon runs - upper Columbia River, 1956 - 57. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 364: 15 p.

HYATT, K. D., M. WRIGHT, and I. MIKI. 1985. 1984 migration patterns, abundance, age, size, and sex composition of Hobiton Lake adult sockeye salmon (Oncorhynchus nerka). Can. Tech. Rep. Fish. Aquat. Sci. 1406: 75 p.

HYATT, K. D. and G. J. STEER. 1987. Barkley Sound sockeye salmon, (Oncorhynchus nerka): evidence for over a century of successful stock development, fisheries management, research, and enhancement efforts. In Sockeye salmon (Oncorhynchus nerka) population biology and future management. Edited by H. D. Smith, L. Margolis, and C. C. Wood. Can. Spec. Publ. Fish. Aquat. Sci. 96: 435 - 457.

HYATT, K. D. and G. J. STEER. 1989. Stock status and 1989 forecasts of Barkley Sound sockeye. Pacific Stock Assessment Review Committee PSARC Working Paper S89-13. Canada Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, British Columbia. 38 p. + 1 Appendix.

LEBRASSEUR, R. J., C. D. MCALLISTER, W. E. BARRACLOUGH, O. D. KENNEDY, J. MANZER, D. ROBINSON, and K. STEVENS. 1978. Enhancement of sockeye salmon (Oncorhynchus nerka) by lake fertilization in Great Central Lake: Summary report. J. Fish. Res. Board Can. 35: 1580 - 1596.

NEILSEN, J. D. and G. H. GEEN. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Trans. Am. Fish. Soc. 110: 554 - 556.

RICKER, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191: xvii + 382 p.

SEBER, G. A. F. 1982. The estimation of animal abundance and related parameters. Second Edition. Charles Griffin and Co. Ltd., London. xvii + 654 p.

SIMPSON, K. 1984. The accuracy of mark-recapture estimates of escapements. In Proceedings of the workshop on stream indexing for salmon escapement estimation, West Vancouver, B.C., 2 - 3 February 1984. pp. 209 - 225. Edited by P. E. K. Symons and M. Waldichuk. Can. Tech. Rep. Fish. Aquat. Sci. 1326: xv + 258 p.

STEER, G. J., N. B. F. COUSENS, H. STIFF, and K. D. HYATT. 1986. An analysis of gear selectivity and sources of bias in estimates of age and stock composition of the 1980 - 1984 Barkley Sound sockeye salmon (Oncorhynchus nerka) catch. Can. Tech. Rep. Fish. Aquat. Sci. 1445: 77 p.

STEER, G. J., N. B. F. COUSENS, H. W. STIFF, K. D. HYATT and D. W. WELSH. 1988. A description of the 1984 fishery, stock composition, and biological characteristics of sockeye salmon (Oncorhynchus nerka) in the catch from Area 23, Barkley Sound. Can. Tech. Rep. Fish. Aquat. Sci. 1667: 78 p.

STEER, G. J. and HYATT, K. D. 1987. Use of a run timing model to provide in-season estimates of sockeye salmon (Oncorhynchus nerka) returns to Barkley Sound. Can. Tech. Rep. Fish. Aquat. Sci. 1557: 39 p.

VAN HYNING, J. M. 1973. Factors affecting the abundance of fall chinook salmon in the Columbia River. Oregon Fish. Comm. Res. Briefs 4: 87 p.

Table 1. Tags applied to adult sockeye to estimate population numbers in Henderson Lake and Clemens Creek in 1988.

		Number Applied		
Tagging Period	Color Code	Males	Females	Total
29 Sep - 1 Oct	orange	246	259	505
6 - 9 Oct	green/yellow	300	331	631
	clear	18	12	30
	red/white	67	116	183
	All	385	459	844
18 - 22 Oct	red/green	295	293	588
	light blue	288	197	485
	dark blue	8	13	21
	All	591	503	1 094
ALL	ALL CODES	1 222	1 221	2 443

Table 2. Visual counts of live sockeye made in six surveys of the Clemens Creek and Henderson Lake spawning grounds in 1988. Numbers with asterisks indicate counts extrapolated for sections not surveyed on the trip of 29 October due to freshets.

	Sockeye Numbers					
Section	29 Sep -1 Oct	6 - 9 Oct	18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
Lake	1 000	900	3 000	3 270*	600	0
1	4 600	7 230	5 700	6 215*	600	1
2	12	105	502	547*	3	0
3	106	1 570	594	647*	47	1
4	330	610	2 280	2 485*	1 300	86
5	200	650	3 050	2 876	483	30
6	0	65	2 200	2 852	176	0
7a	0	0	0	10	0	0
7b	0	0	0	20	0	0
ALL	6 248	11 130	17 346	18 925	3 209	118

Table 3. Counts of dead sockeye pitched from Clemens Creek during four visual surveys of the Henderson Lake spawning grounds in 1988. Numbers with asterisks indicate counts extrapolated for sections not surveyed on the trip of 29 October due to freshets. The ratio of numbers counted in sections 5 and 6 between the surveys of 18 and 29 October were used to make the extrapolations. Only 128 sockeye were actually pitched during the trip of 29 October (sections 5, 6, and 7 were the only ones covered).

	Numbers of Dead Sockeye Pitched			
Stream Section	18 - 22 Oct	29 Oct - 1 Nov	14 - 17 Nov	28 - 30 Nov
1	37	128*	1 001	267
2	2	7*	23	25
3	15	52*	71	98
4	114	394*	601	214
5	18	81	279	84
6	19	47	110	0
7a	0	0	0	0
7b	0	0	0	0
ALL	**205**	**709**	**2 085**	**688**

Table 4. Numbers of live sockeye bearing tags enumerated in four visual surveys of the spawning grounds in Clemens Creek, 1988. Counts are given separately for each tag color, stream survey section, and tag-recovery period.

Tag Color	Survey Section	Numbers of Tagged, Live Sockeye Counted			
		18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
orange	1	0	-	0	0
	2	1	-	0	0
	3	5	-	0	0
	4	23	-	3	0
	5	31	14	0	0
	6	29	8	0	0
	7	0	0	0	0
	All	**89**	**22**	**3**	**0**
green/ yellow	1	0	-	1	0
	2	2	-	0	0
	3	5	-	1	0
	4	24	-	5	0
	5	28	16	1	0
	6	15	4	0	0
	7	0	0	0	0
	All	**74**	**20**	**8**	**0**
clear*	1	0	-	0	0
	2	0	-	0	0
	3	0	-	0	0
	4	0	-	0	0
	5	0	0	0	0
	6	0	0	0	0
	7	0	0	0	0
	All	**0**	**0**	**0**	**0**
red/ white	1	0	-	0	0
	2	1	-	0	0
	3	3	-	0	0
	4	7	-	0	0
	5	9	0	0	0
	6	5	0	0	0
	7	0	0	0	0
	All	**25**	**0**	**0**	**0**

Table 4. (continued).

Tag Color	Survey Section	Numbers of Tagged, Live Sockeye Counted: 18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
red/ green	1	0	-	8	0
	2	0	-	0	0
	3	0	-	1	0
	4	0	-	50	0
	5	0	30	6	0
	6	0	17	3	0
	7	0	0	0	0
	All	**0**	**47**	**68**	**0**
light blue	1	1	-	5	0
	2	1	-	1	0
	3	0	-	1	0
	4	0	-	29	1
	5	0	12	3	0
	6	0	9	1	0
	7	0	0	0	0
	All	**2**	**21**	**40**	**1**
dark blue	1	0	-	0	0
	2	0	-	0	0
	3	0	-	0	0
	4	0	-	2	0
	5	0	2	0	0
	6	0	0	0	0
	7	0	0	0	0
	All	**0**	**2**	**2**	**0**
TOTAL	**ALL**	**190**	**112**	**121**	**1**

* Clear tags were excluded from all computations involving visual recoveries of live, tagged fish.

Table 5. Comparison of tag-detection efficiencies between small-diameter (19-mm) tags applied to sockeye in 1988 and large (25-mm) tags employed in 1987. The mean percentage of tags observed relative to the numbers applied provides a measure of visual detection efficiency for each tag type (see text). Large, single-colored tags were > 2.8-times more detectable than small, variably colored ones.

Year	Survey Date	Cumulative No. of Tags Released	Days Elapsed Since First Tagging	Number of Tags Counted	Percentage of Applied Tags Detected
1988	1 Oct	505	0	0	0
	7 Oct	505	6	no data	no data
	20 Oct	1 319[a]	19	188	14.3
	25 Oct	1 319	24	428[b]	32.4
	30 Oct	2 413[a]	29	544[c]	22.5
	16 Nov	2 413	45	121	5.0
	29 Nov	2 413	58	1	0.0[d]
1987	26 Sep	90	0	0	0
	7 Oct	90	11	46	51.1
	15 Oct	246	19	135	54.9
	24 Oct	513	28	289	56.3
	3 Nov	1 992	38	972	48.8

Mean Percent Detected (± 95 % CI): 1987 - 52.8 ± 4.7
1988 - 18.6 ± 16.1

[a] Clear tags were excluded from total numbers of tags applied.
[b] Based on strip count estimates and determined from the ratio of tagged-to-untagged fish found from total-section counts made on the same day.
[c] Expanded value to correct for incomplete coverage of survey sections (see text).
[d] Excluded from mean (high no. of days elapsed since tagging).

Table 6. Numbers of dead sockeye bearing tags in four surveys of the spawning grounds in Clemens Creek, 1988. Tagged carcasses are tallied separately for each tag color, stream survey section, and tag-recovery period.

Tag Color	Survey Section	Numbers of Tagged Carcasses Recovered			
		18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
orange	1	5	-	7	0
	2	0	-	0	0
	3	1	-	1	0
	4	5	-	1	1
	5	2	4	2	0
	6	0	2	0	0
	7	0	0	0	0
	All	**13**	**6**	**11**	**1**
green/ yellow	1	0	-	7	1
	2	0	-	0	0
	3	0	-	1	0
	4	4	-	2	0
	5	0	2	0	0
	6	1	0	1	0
	7	0	0	0	0
	All	**5**	**2**	**11**	**1**
clear	1	0	-	0	0
	2	0	-	0	0
	3	0	-	0	0
	4	1	-	0	0
	5	0	0	0	0
	6	0	0	0	0
	7	0	0	0	0
	All	**1**	**0**	**0**	**0**
red/ white	1	0	-	0	0
	2	1	-	0	0
	3	0	-	0	0
	4	0	-	2	0
	5	0	1	0	0
	6	1	0	1	0
	7	0	0	0	0
	All	**2**	**1**	**3**	**0**

Table 6. (continued).

Tag Color	Survey Section	Numbers of Tagged Carcasses Recovered 18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
red/ green	1	0	-	18	0
	2	0	-	0	0
	3	0	-	0	0
	4	0	-	3	0
	5	0	0	0	0
	6	0	0	0	0
	7	0	0	0	2
	All	**0**	**0**	**21**	**2**
light blue	1	0	-	8	5
	2	0	-	0	0
	3	0	-	1	0
	4	0	-	3	0
	5	0	0	0	0
	6	0	0	0	0
	7	0	0	0	0
	All	**0**	**0**	**12**	**5**
dark blue	1	0	-	0	0
	2	0	-	0	0
	3	0	-	0	0
	4	0	-	0	0
	5	0	0	0	0
	6	0	0	0	0
	7	0	0	0	0
	All	**0**	**0**	**0**	**0**
TOTAL	**ALL**	**21**	**9**	**58**	**9**

Table 7. Spawner residence time on the Henderson Lake and Clemens Creek spawning grounds based upon the unadjusted cumulative tag-day method. Total tag-days were determined for each tag group by integrating the area under the curve formed from the numbers of tagged, live fish enumerated during visual surveys. Areas were determined separately for each survey interval and then summed. The first point on each curve (day 0) was the total number of tags applied. Thirty clear tags applied on 7 October were not included in the determination of mean spawner residence time because these tags were difficult to observe on live fish.

(i) ORANGE TAGS

	Tags Applied	Tags Recovered			
	1 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	505	89	33[a]	3	0
Survey Interval (d)		19	10	17	13
Integrated AUC Interval (tag-d)		5643	610	306	19.5

Cumulative tag-d: **6 578.5**

No. of Tags Applied: **505**

Residence Time (Σ tag-d / no. tags applied): **13.0 d**

Table 7. (continued).

(ii) GREEN/YELLOW + RED/WHITE TAGS

	Tags Applied	Tags Recovered			
	7 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	814	99	45[a]	8	0
Survey Interval (d)		13	10	17	13
Integrated AUC Interval (tag-d)		5934.5	720	450.5	52

Cumulative tag-d: 7 157
No. of Tags Applied: 814

Residence Time (Σ tag-d / no. tags applied): **8.8 d**

(iii) RED/GREEN + LIGHT BLUE + DARK BLUE TAGS

	Tags Applied	Tags Recovered			
	20 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	1 094	2[b]	466[a]	110	1
Survey Interval (d)		10	14	7	
Integrated AUC Interval (tag-d)		7800	4896	722[c]	

Cumulative tag-d: 13 418
No. of Tags Applied: 1 094

Residence Time (Σ tag-d / no. tags applied): **12.3 d**

Table 7. (continued).

(iv) ALL TAGS AVERAGED

Mean Spawner Residence Time: 11.4 d

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[a] Counts expanded to account for sections not surveyed due to freshets. Numbers for unsurveyed sections were estimated from proportions of total counts found in those reaches during the surveys of 18 October for orange, green/yellow, and red/white tags and 14 November for red/green, light blue, and dark blue tags (see text). Only 22 orange, 20 green/yellow plus red/white, and 70 red/green, light blue, and dark blue tags were actually observed on 30 October.

[b] Omit from tag abundance curve.

[c] Includes 0.5 tag-day from the linear extrapolation of the curve beyond the last survey date of 29 November.

Table 8. Spawner residence time on the Henderson Lake and Clemens Creek spawning grounds based upon the adjusted cumulative tag-day method. Recoveries of tagged, live sockeye were adjusted upward by a factor of 2.84 to account for reduced visual detection efficiencies in 1988 due to the use of small-diameter tags (see text and Table 5). Total tag-days were determined for each tag group as detailed in Table 7.

(i) ORANGE TAGS

	Tags Applied	Adjusted No. of Tags Recovered			
	1 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	505	253	94[a]	9	0
Survey Interval (d)		19	10	17	13
Integrated AUC Interval (tag-d)		7201	1735	875.5	58.5

Cumulative tag-d: **9 870**

No. of Tags Applied: **505**

Residence Time (Σ tag-d / no. tags applied): **19.5 d**

Table 8. (continued).

(ii) GREEN/YELLOW + RED/WHITE TAGS

	Tags Applied	Adjusted No. of Tags Recovered			
	7 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	814	281	128[a]	23	0
Survey Interval (d)		13	10	17	13
Integrated AUC Interval (tag-d)		7117.5	2045	1283.5	149.5

Cumulative tag-d: **10 595.5**
No. of Tags Applied: **814**

Residence Time (Σ tag-d / no. tags applied): **13.0 d**

(iii) RED/GREEN + LIGHT BLUE + DARK BLUE TAGS

	Tags Applied	Adjusted No. of Tags Recovered			
	20 Oct	20 Oct	30 Oct	16 Nov	29 Nov
	1 094	6[b]	1094[a,c]	312	3
Survey Interval (d)		10	14	7	
Integrated AUC Interval (tag-d)		10 940[c]	11 951[c]	2049[d]	

Cumulative tag-d: **24 940**
No. of Tags Applied: **1 094**

Residence Time (Σ tag-d / no. tags applied): **22.8 d**

Table 8. (continued).

(iv) ALL TAGS AVERAGED

Mean Spawner Residence Time: 18.4 d

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[a] Counts also expanded to account for sections not surveyed due to freshets (see Table 7).

[b] Omit from tag abundance curve.

[c] Tag recoveries and subsequent cumulative tag-days and residence times clearly overestimated due to the application of two independent expansions for 30 October.

[d] Includes 1.5 tag-days from the linear extrapolation of the curve beyond the last survey date of 29 November.

Table 9. Mean stream residence time of sockeye spawners based upon the adjusted tag-depletion method. Tag recoveries were adjusted upward to compensate for low tag-detection efficiencies resulting from the use of small-diameter tags. Residence time was determined for each sockeye tag group by using regressions in which the y-axis intercept was both unconstrained and constrained by the true numbers of tags initially applied (see text). For unconstrained regressions, the estimated time (days) to reach 50 % tag loss ($E_{TL}50$) was determined from initial tag numbers (E_{TS}) estimated from parameters of each regression equation. DE = no. of days elapsed; n = no. of tag-recovery observations.

(A) Regressions Unconstrained by Initial Number of Tags

Tag Group	Tag-Depletion Regression	$E_{TL}50$ (d) (Stream Residence Time)
orange (1 Oct)	Ln(Tags+1) = -0.138(DE) + 8.386 r^2 = 0.989; $p < 0.01$; n = 4; E_{TS} = 4 385 tags	5.0
green/ yellow; red/white (7 Oct)	Ln(Tags+1) = -0.136(DE) + 7.812 r^2 = 0.936; $p < 0.05$; n = 4; E_{TS} = 2 470 tags	5.1
red/green; light blue; dark blue (20 Oct)	Ln(Tags+1) = -0.181(DE) + 9.366 r^2 = 0.858; $p > 0.05$; n = 3; E_{TS} = 11 686 tags	3.8

Mean Stream Residence Time: **4.6 d**

Table 9. (continued).

(B) Regressions Constrained by Initial Number of Tags

Tag Group	Tag-Depletion Regression	$E_{TL}50$ (d) (Stream Residence Time)
orange (1 Oct)	Ln(Tags+1) = -0.109(DE) + 7.080 r^2 = 0.934; p < 0.001; n = 5;	14.2
green/ yellow; red/white (7 Oct)	Ln(Tags+1) = -0.084(DE) + 6.770 r^2 = 0.999; p < 0.001; n = 5;	9.1
red/green; light blue; dark blue (20 Oct)	Ln(Tags+1) = -0.137(DE) + 7.952 r^2 = 0.800; p < 0.05; n = 4;	12.0

Mean Stream Residence Time: 11.8 d

Table 10. Visual enumeration of live and dead sockeye at the Henderson Lake spawning grounds, 1988. Peak counts of live-plus-dead fish were estimated for the survey of 29 October. Numbers with asterisks denote totals derived by extrapolating counts for the lake and stream sections 1 - 4 which were not surveyed due to freshets (see Tables 2 and 3).

	Sockeye Numbers					
	29 Sep -1 Oct	6 - 9 Oct	18 - 22 Oct	29 Oct -1 Nov	14 - 17 Nov	28 - 30 Nov
Live Sockeye	6 248	11 130	17 346	18 925*	3 209	118
Dead Sockeye	0	0	205	709*	2 085	688
Total Count	6 248	11 130	17 551	**19 634**	5 294	806

Table 11. Summary of escapement estimates for Henderson Lake sockeye, 1988. Some residence times were calculated after tag recoveries were adjusted to account for low visual detection efficiencies associated with the use of small-diameter tags. AUC = integrated area under a spawner abundance curve.

Method	Residence Time (d)	Population Estimate
Peak Count of Live + Dead Fish	-	19 634
AUC + Interval Between Peak Counts of Live and Dead Fish	18.0	38 302
AUC + Cumulative Tag-Days: Tag Visibility Adjusted	18.4	37 469
AUC + Cumulative Tag-Days: Tag Visibility Unadjusted	11.4	60 476
AUC + Constrained Tag-Depletion Regressions: Tag Visibility Adjusted	11.8	58 426
Simple Petersen Mark-Recapture: Live Fish, Tag Visibility Adjusted	-	52 972
Stratified Petersen Mark-Recapture: Live Fish: Tag Visibility Adjusted	-	52 118
Simple Petersen Mark-Recapture: Carcasses	-	78 226
Stratified Petersen Mark-Recapture: Carcasses	-	80 963

Table 12. Age and sex composition of sockeye escapement samples collected from Clemens Creek in 1988. Numbers in parentheses are percentages of the total samples consisting of each age-sex category.

Sampling Date	Sample (N)	Sex	Age 1.2	1.3	1.4	All
30 Sep - 1 Oct	92	M	9 (9.8)	37 (40.2)	0 (0)	46 (50.0)
		F	18 (19.6)	28 (30.4)	0 (0)	46 (50.0)
		All	27 (29.3)	65 (70.7)	0 (0)	92 (100)
22 Oct	71	M	8 (11.3)	29 (40.8)	0 (0)	37 (52.1)
		F	14 (19.7)	19 (26.8)	1 (1.4)	34 (47.9)
		All	22 (31.0)	48 (67.6)	1 (1.4)	71 (100)
1988 Total	163	M	17 (10.4)	66 (40.5)	0 (0)	83 (50.9)
		F	32 (19.6)	47 (28.8)	1 (0.6)	80 (49.1)
		All	49 (30.1)	113 (69.3)	1 (0.6)	163 (100)

Table 13. Length-frequency distributions of sockeye escapement samples collected from Clemens Creek in 1988. Mean postorbital-hypural lengths (mm) are provided with ± 95 % confidence limits.

Sampling Date	Sample (N)	Sex	Age 1.2	Age 1.3	Age 1.4
30 Sep - 1 Oct	92	M	438.1 ± 15.9	509.1 ± 8.4	-
		F	441.7 ± 13.1	501.8 ± 10.0	-
22 Oct	71	M	447.1 ± 22.8	497.4 ± 30.7	-
		F	449.4 ± 12.8	495.8 ± 10.3	457 -
1988 Total	163	M	442.3 ± 12.2	503.9 ± 6.9	-
		F	445.1 ± 8.8	499.3 ± 7.0	457 -

Table 14. Mean escapements, catches by the Area 23 commercial net fishery, and total returns of Henderson Lake sockeye salmon, 1980 - 1987. Estimates for all years but 1980 employed visual counts combined with Petersen mark-recapture techniques (see text). The 1980 escapement was estimated from a series of simple visual counts.[1] The simple Petersen estimate for 1988 (based on live fish) is compared with the mean for the previous eight years. Catches were allocated to the Henderson Lake stock through analyses using parasite infection frequencies characteristic of sockeye originating from Great Central, Sproat, and Henderson lakes (see Steer et al. 1988). All means are provided with ± standard deviations.

	1980 - 1987			1988
	Mean	SD	Range	Simple Petersen
Escapement	32 384	± 16 010	6 767 - 56 065	52 172
Commercial Net Catch	37 430	± 33 401	0 - 85 250	50 152
Total Sockeye Returns to Henderson Lake	69 814	± 43 090	6 767 - 128 430	102 324[2]

[1] The peak count of 20 760 live-plus-dead sockeye, considered to represent the 1980 escapement, was made in late October at the beginning of spawner mortality. No additional immigration into the system was presumed.

[2] Based on the preferred (AUC) escapement estimate of 38 302 sockeye for 1988, total returns to Henderson Lake would be 88 454 fish.

Table 15. Mean age composition of escapements and Area 23 commercial net catch of Henderson Lake sockeye from 1980 - 1987. Data for 1988 are included for comparison with the multiple-year means. Age distributions of escapements were determined from annual samples containing 95 - 300 fish. Between 9 - 68 fish were assigned to the Henderson Lake stock and to specific ages from samples of 193 - 1 683 sockeye taken annually from the commercial net catch. Proportions of the catch consisting of four and five-year-old Henderson Lake sockeye were then determined from this sample information through least squares regression analyses employing parasite infection frequencies characteristic of sockeye originating from Great Central, Sproat, and Henderson lakes. Proportions of the catch not assigned by this method to ages 4 or 5 were summed into a category assumed to contain three and six-year-olds (see Steer et al. 1988).

		1980 - 1987			
	Age Class	Mean	SD	Range	1988
Escapement	3	0.001	± 0.002	0 - 0.004	0
	4	0.353	± 0.223	0.085 - 0.760	0.301
	5	0.620	± 0.226	0.230 - 0.884	0.693
	6	0.021	± 0.040	0 - 0.117	0.006
Commercial Net Catch	3,6	0.066	± 0.077	0.012 - 0.234	0
	4	0.285	± 0.144	0.104 - 0.559	0.252
	5	0.649	± 0.202	0.207 - 0.883	0.748

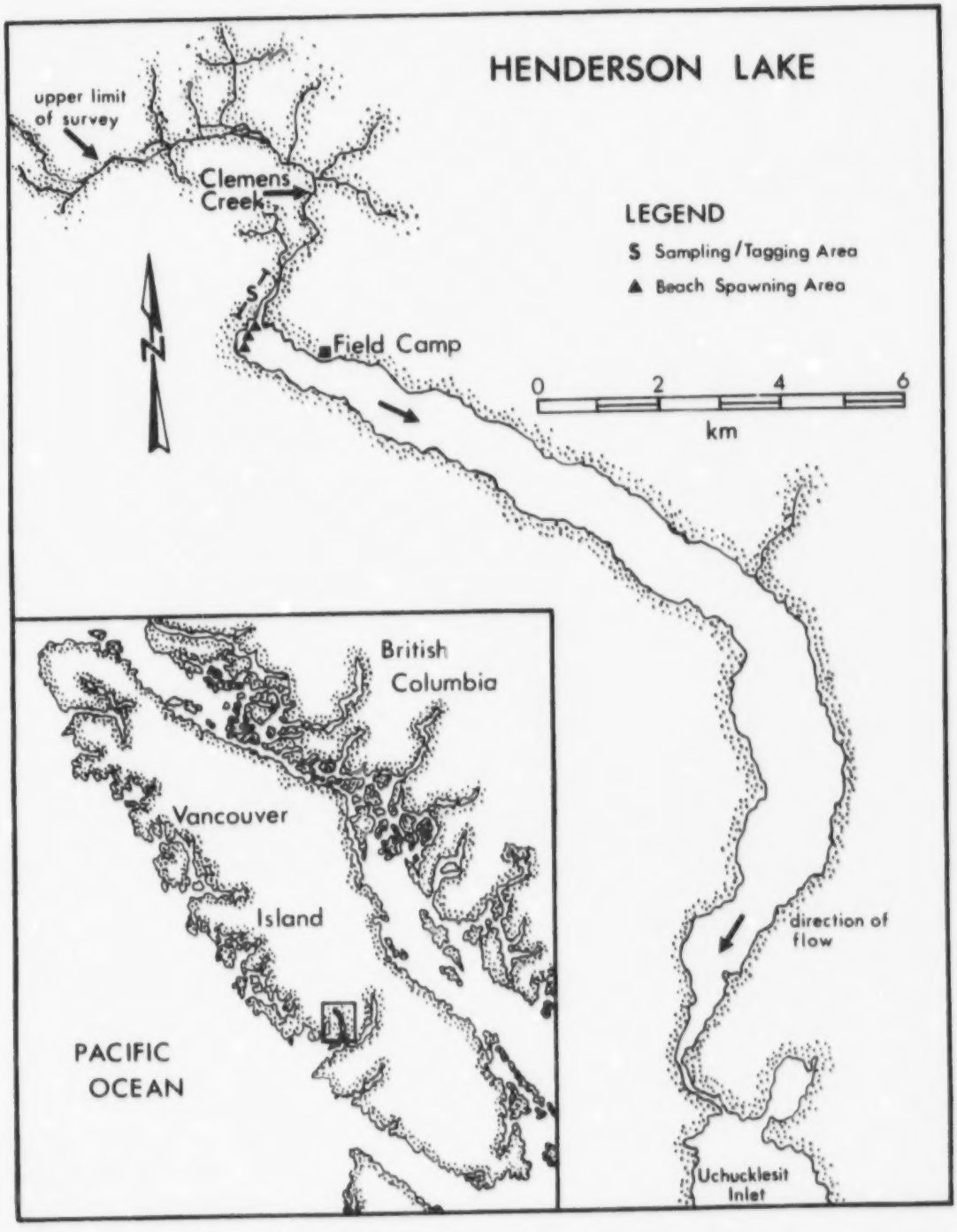


Fig. 1. Location of Henderson Lake and Clemens Creek study area adjacent to Barkley Sound, Vancouver Island.

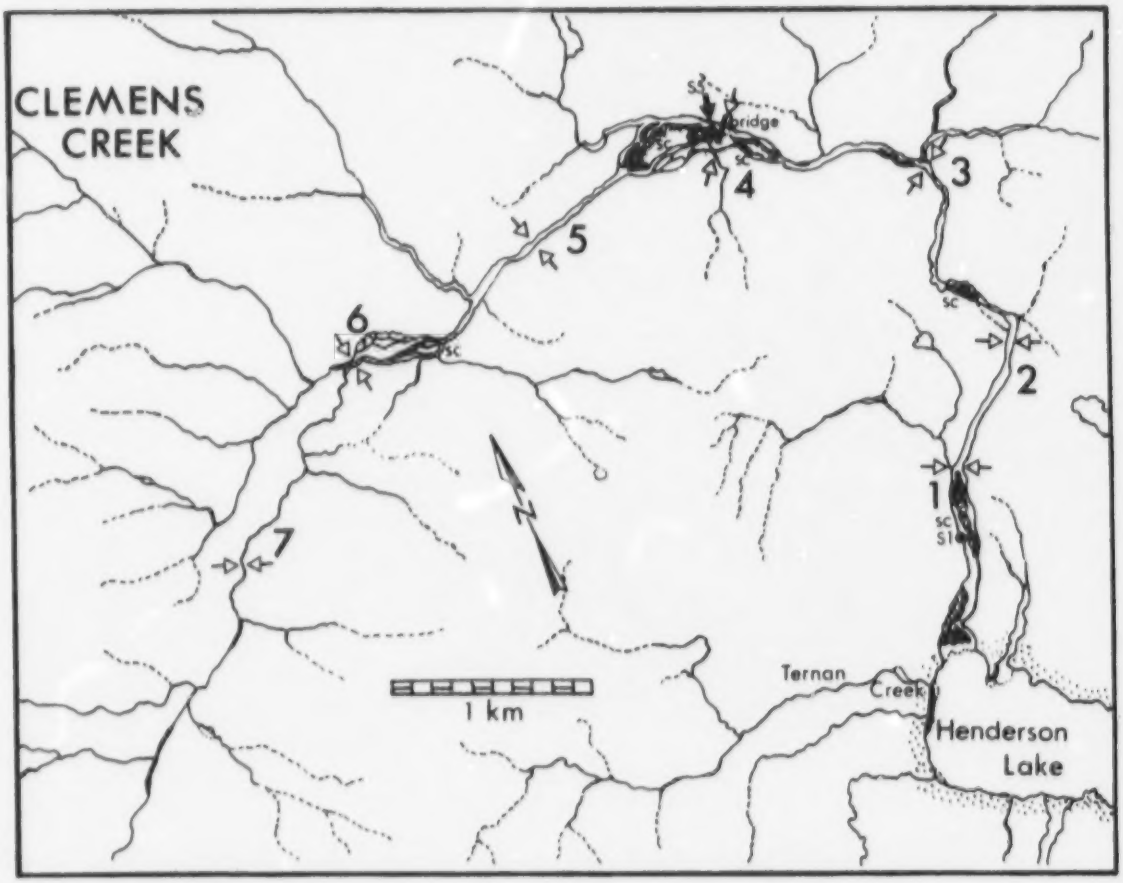


Fig. 2. Detailed map of the spawner survey sections in Clemens Creek. Numbers and arrows mark the upstream end of each study section. Sections were approximately 1 km long on average. Major side channels containing sockeye are denoted by sc. Sections 1 and 5 staff-gauge locations are denoted by S1 and S5 respectively. Sockeye were enumerated separately in each section and along the lakehead beach of Henderson Lake.

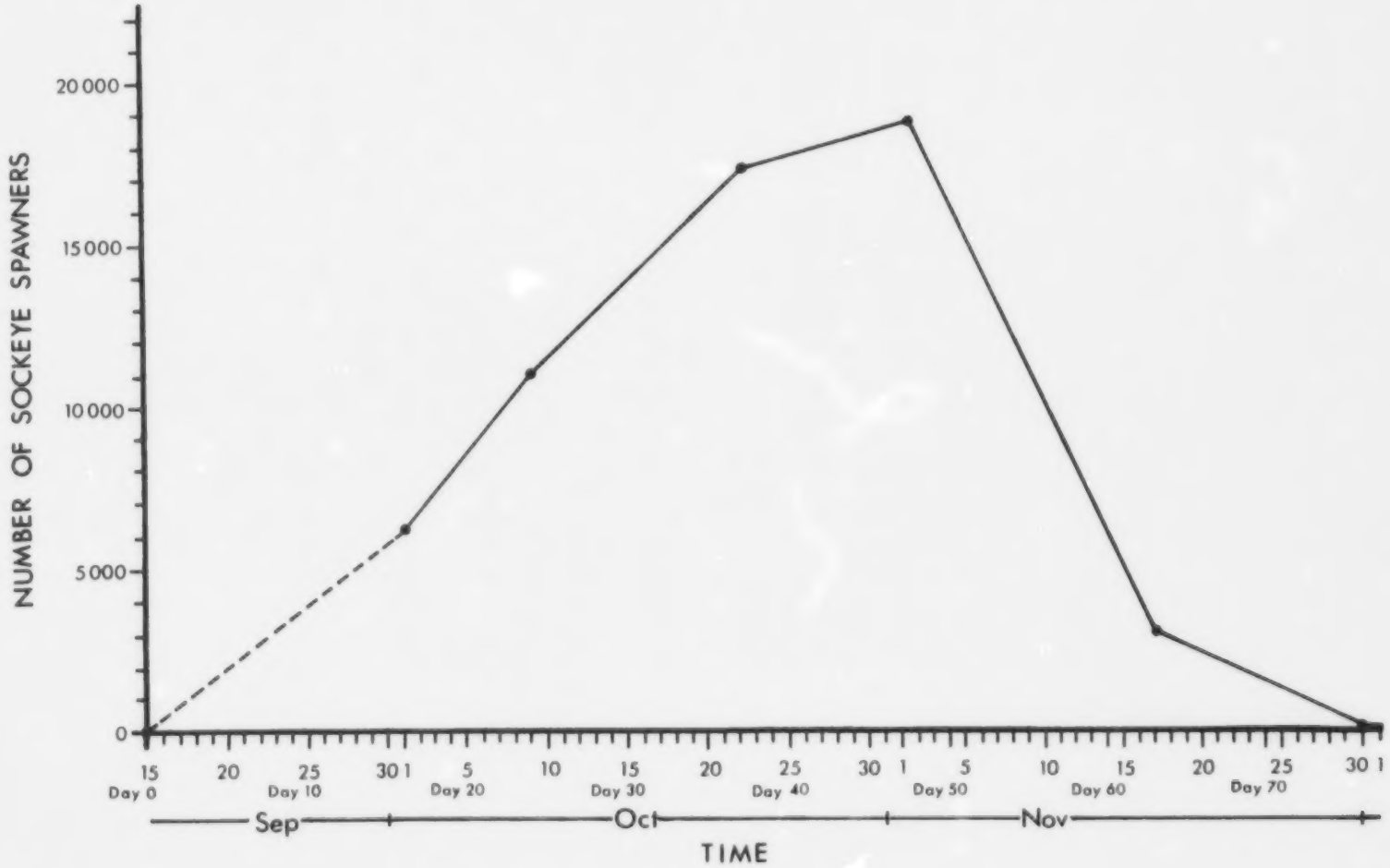


Fig. 3. Numbers of live, adult sockeye enumerated visually in six surveys of the Henderson Lake and Clemens Creek spawning grounds during 1988. Dashed line indicates an extrapolation to the date of sockeye arrival at the spawning grounds. Data points are plotted as the last day of each survey.

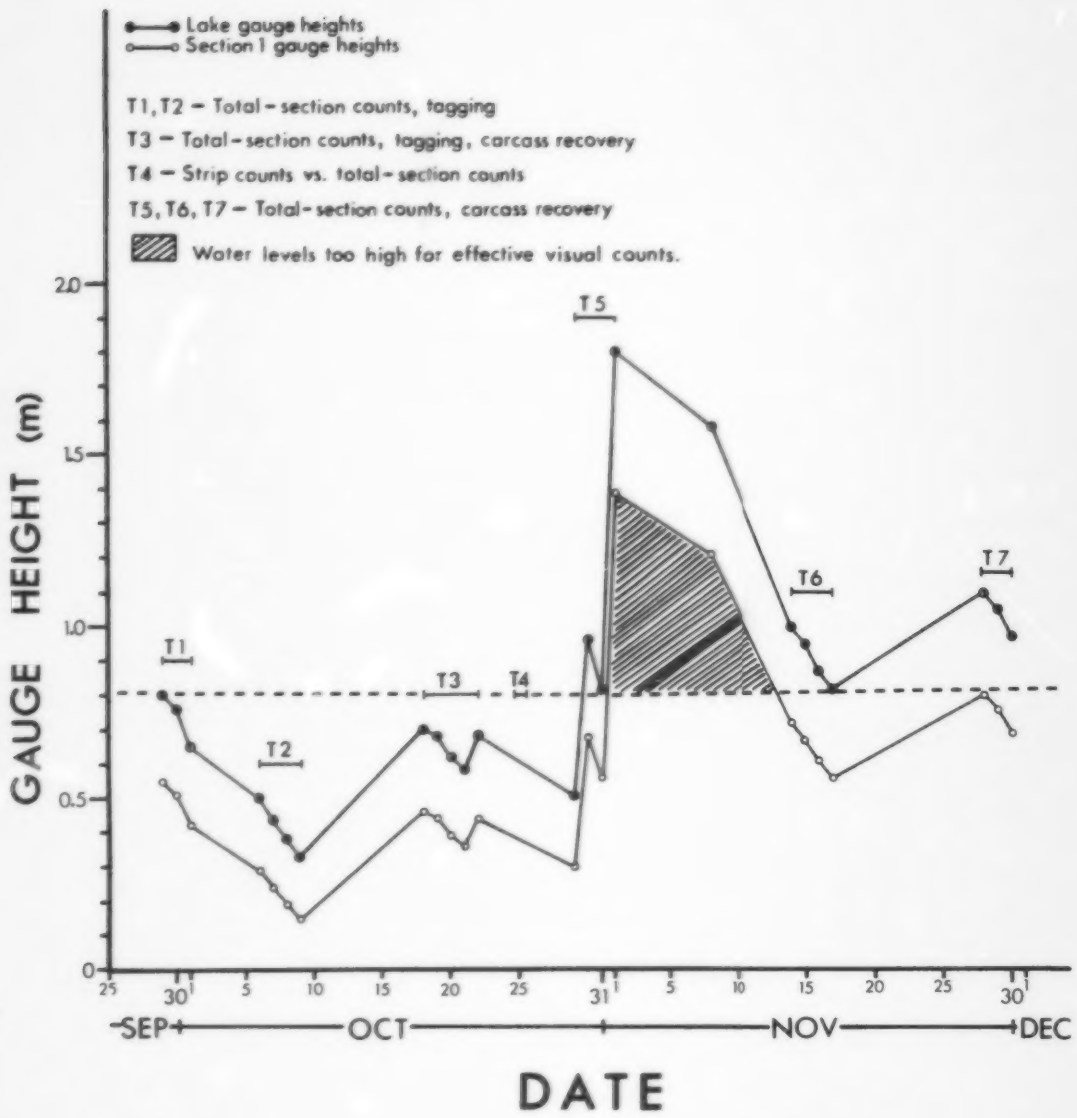


Fig. 4. Variations in staff gauge height (m) in Henderson Lake and Clemens Creek during surveys in 1988. Lake gauge heights are direct readings made in 1988. Stream gauge heights for 1988 are based on a regression between lake gauge and section 1 gauge heights developed in 1984 (see text, Appendix Table A-1). Durations of seven separate surveys of the spawning grounds are indicated as T1 - T7.

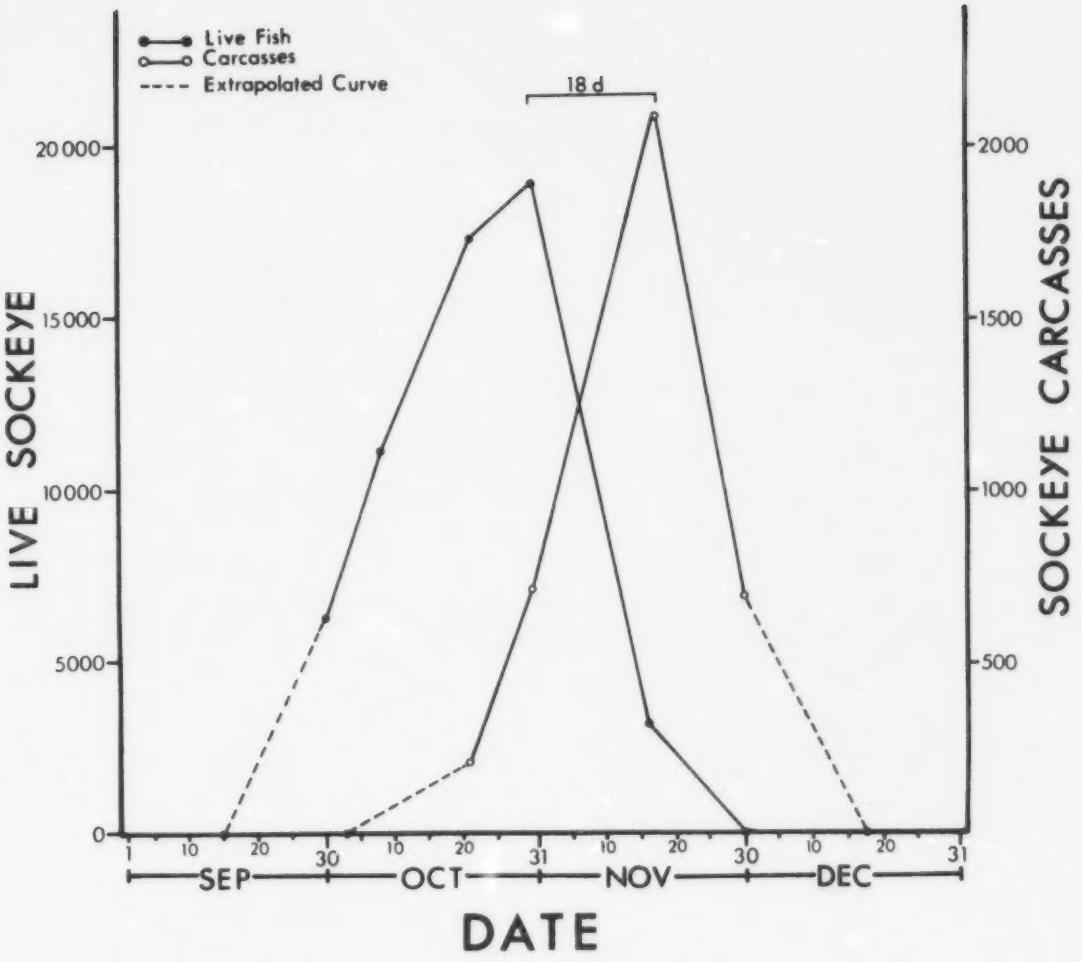
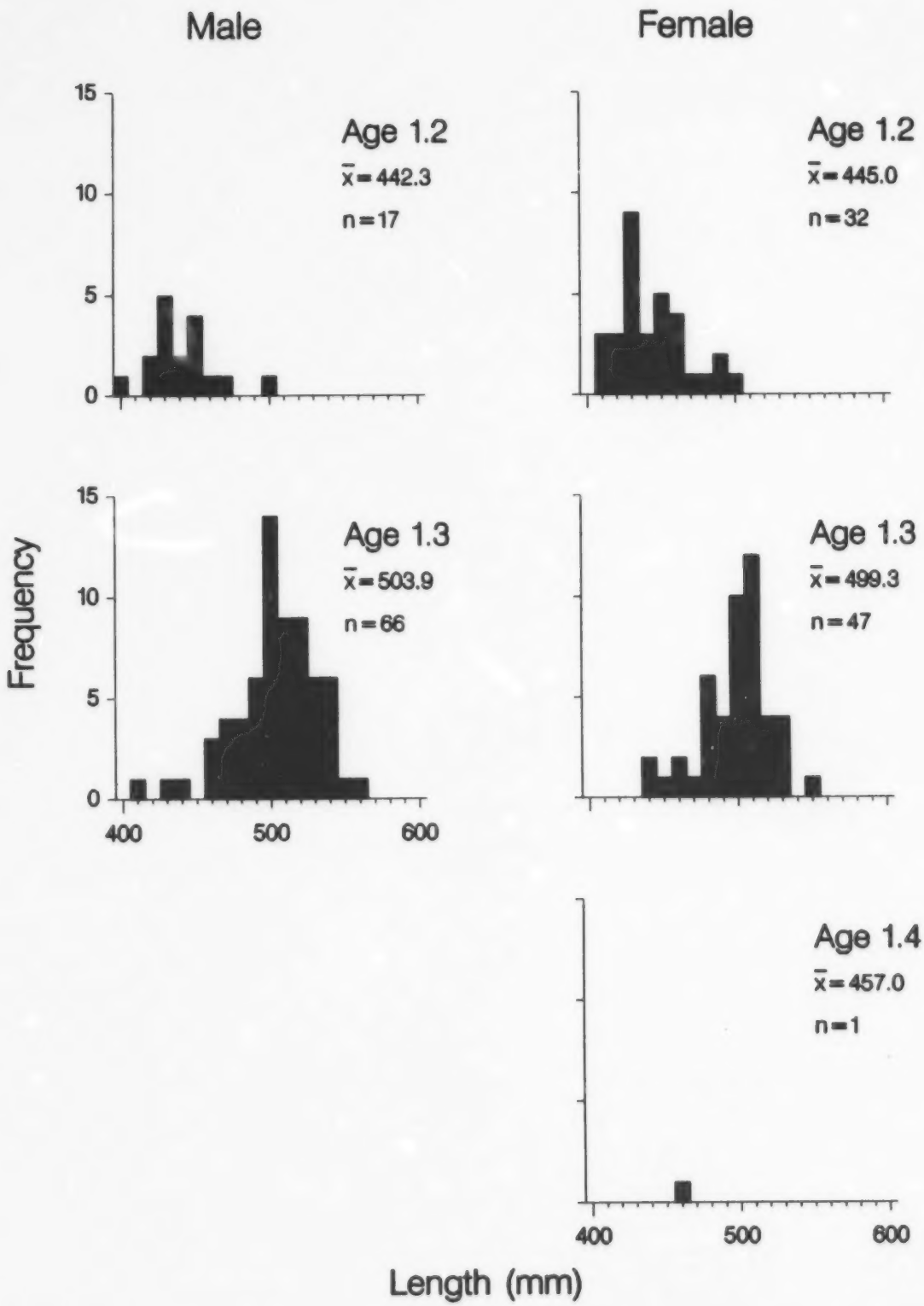


Fig. 5. Sequential estimates of live and dead sockeye used to determine mean spawner residence time from the interval between peak counts of live and dead fish.

Fig. 6. Length frequencies of sockeye spawners at Henderson Lake and Clemens Creek, 1988. Mean postorbital-hypural lengths are given for males and females of each age group sampled from section 1 of the creek. Sample size is denoted by n.

1988 Henderson Lk Sockeye
Length Frequency



APPENDICES

Table A-1. Staff gauge readings (m) for relative water levels at Henderson Lake Camp and Clemens Creek stations (stream sections 1 and 5). Observation dates are grouped according to visual survey periods.

Observation Date	Station			
	Henderson Lake Gauge at Camp	Section 1	Section 1; 1984 Gauge Equivalents[b]	Section 5
29 Sep	0.80	-	0.55	-
30 Sep	0.76	-	0.51	-
1 Oct	0.65	-	0.42	0.15
6 Oct	0.50	-	0.29	-
7 Oct	0.44	-	0.24	-
8 Oct	0.38	-	0.19	0.00
9 Oct	0.33	-	0.15	-
18 Oct	0.70	0.19	0.46	-
19 Oct	0.68	0.18	0.44	-
20 Oct	0.62	0.15	0.39	-
21 Oct	0.58	0.25	0.36	0.25
22 Oct	0.68	0.28	0.44	-
29 Oct	0.51	0.17	0.30	-
30 Oct	0.96	-	0.68	-
31 Oct	0.82	1.25	0.56	-
1 Nov	1.80	-	1.39	-
8 Nov	1.58	1.50	1.21	-
14 Nov	1.00	-[a]	0.72	-
15 Nov	0.95	-	0.67	0.26
16 Nov	0.87	-	0.61	0.27
17 Nov	0.82	-	0.56	-
28 Nov	1.10	-	0.80	-
29 Nov	1.05	-	0.76	0.27
30 Nov	0.97	-	0.69	-

[a] Staff gauge in section 1 was washed out by strong freshets.

[b] Equivalent gauge heights for section 1 in 1988 were derived on the basis of a linear regression between lake gauge heights (LkGH) and section 1 gauge heights (S1GH) for 1984:

$S1GH\ (cm) + 100 = 0.845 \times LkGH\ (cm) + 87.04$ ($r^2 = 0.89$; $p < 0.001$; $n = 51$).

Table A-2. Comparison of sockeye abundance estimated for Clemens Creek by total-section counts and within-section expansions based upon strip counts. Counts by both methods were made on 25 Oct 1988. The percentage of the total sockeye population estimated for the entire stream is given for each sectional estimate and count type. Strip counts include live fish only.

Stream Section	Strip Count	Percent of Total	Complete Count	Percent of Total	Mean Count	Percent of Total
1	2 578	19	2 945	23	2 761	21
2	597	4	451	4	524	4
3	774	6	1 006	8	890	7
4	4 450	32	3 511	27	4 065	30
5	3 480	25	2 557	20	3 056	23
6	1 876	14	2 266	18	2 071	15
7	-	-	98	1	98	1
ALL	**13 755**	**100**	**12 833***	**100**	**13 465**	**100**

* Count includes 399 tagged fish.

Table A-3. Numbers of live and dead sockeye enumerated by using the strip-count method in six survey sections of Clemens Creek on 25 October 1988. Numbers of fish counted in each one-meter strip are included with observations of tagged, live fish and comments on visibility. The live-fish category refers to untagged sockeye. Actual tag colors applied: O = orange, R/W = red/white, R/G = red/green, G/Y = green/yellow, Lt.B = light blue. Observer-interpreted colors not actually applied as tags (in quotations): R = red, G = green, B = blue, G/W = green/white.

Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
1	1	0	0	1 "R"	1	Actual color =
	2	0	0	0	0	R/G?
	3	0	0	0	0	
	4	0	0	0	0	Poor visibility
	5	7	0	0	7	at strip 4.
	6	0	0	0	0	
	7	0	0	0	0	
	8	0	0	0	0	
	9	0	0	0	0	
	10	1	0	1 "G"	1	Actual color =
	11	3	0	0	3	G/Y?
	12	2	0	0	2	
	13	5	0	0	5	
	14	6	0	0	6	
	15	0	0	0	0	
	16	3	0	0	3	
	17	4	0	0	4	
	18	0	0	0	0	No visibility at
	19	0	0	0	0	strips 18 - 20
	20	0	0	0	0	due to rippled
	21	8	0	0	8	water surface.
	22	3	0	0	3	
	23	12	0	0	12	
	24	3	0	0	3	
	25	18	0	0	18	
	26	0	0	0	0	
2	1	0	0	0	0	
	2	0	0	0	0	
	3	0	0	0	0	
	4	0	0	0	0	
	5	0	0	0	0	
	6	0	0	0	0	
	7	0	0	0	0	

Table A-3. (continued).

Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
2	8	0	0	0	0	
	9	0	0	0	0	
	10	4	0	1	5	Tag color not
	11	2	0	0	2	recorded.
	12	5	0	1 "B"	6	Actual color =
	13	1	0	0	1	Lt.B for strip
	14	0	0	0	0	12?
	15	1	0	0	1	
	16	0	0	0	0	
	17	1	0	0	1	
	18	1	0	0	1	
	19	0	0	0	0	
3	1	0	0	0	0	
	2	0	0	0	0	
	3	0	0	0	0	
	4	0	0	0	0	
	5	0	0	1 "G/W"	1	Actual color =
	6	2	0	0	2	G/Y?
	7	0	0	0	0	
	8	0	0	0	0	
	9	0	0	0	0	
	10	1	0	0	1	
	11	0	0	0	0	
	12	0	0	0	0	
	13	0	0	0	0	
	14	0	0	0	0	
	15	0	0	0	0	
	16	0	0	0	0	
	17	3	0	0	3	
	18	0	0	0	0	Visibility at
	19	4	0	0	4	strip 18 into
	20	0	0	0	0	large pool about
	21	0	0	0	0	30 %.
	22	3	0	0	3	Ambient light
	23	0	0	0	0	very poor in
	24	0	0	0	0	showers.
	25	0	0	0	0	
	26	0	0	0	0	
	27	0	0	0	0	
	28	0	0	0	0	
	29	1	0	0	1	
	30	1	0	0	1	Visibility at
	31	0	0	0	0	strip 33 into
	32	3	0	0	3	fast-flowing
	33	4	0	0	4	pool about 50 %.

Table A-3. (continued).

Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
3	34	0	0	0	0	
4	1	7	0	1 "G/W"	8	Actual color =
	2	11	0	1 O	12	G/Y in strip 1?
	3	5	0	0	5	
	4	12	0	0	12	
	5	5	0	0	5	
	6	9	0	0	9	
	7	6	0	1	7	Tag color not
	8	3	0	0	3	recorded.
	9	1	0	0	1	Visibility in
	10	4	0	0	4	strip 8 about
	11	0	0	0	0	80 %.
	12	0	0	0	0	
	13	2	0	0	2	
	14	0	0	0	0	
	15	1	0	0	1	
	16	0	1	0	1	
	17	4	0	0	4	
	18	5	0	0	5	
	19	2	0	0	2	
	20	3	0	0	3	
	21	4	0	0	4	
	22	10	0	0	10	
	23	9	0	0	9	
	24	8	2	0	10	
	25	2	0	0	2	Poor visibility
	26	0	0	0	0	(about 50 %) in
	27	1	1	0	2	strip 25 at
	28	1	0	0	1	12:20 h.
	29	2	0	0	2	
	30	2	0	0	2	
	31	4	0	1 R/G	5	
	32	2	2	0	4	
	33	0	0	0	0	
	34	0	0	0	0	
	35	1	1	0	2	Section finished
	36	2	0	0	2	at 12:40 h.
5	1	4	0	0	4	Sections 5 and 6
	2	3	0	0	3	surveyed under
	3	6	0	0	6	light drizzle.
	4	0	0	0	0	Sky overcast
	5	1	0	0	1	(10/10). Light
	6	0	0	0	0	level was low.
	7	2	0	0	2	Water was 9.0°C.

Table A-3. (continued).

Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
5	8	5	0	0	5	
	9	9	0	0	9	
	10	6	0	0	6	
	11	6	0	1 "R"	7	Actual color =
	12	15	0	0	15	R/G? Visibility
	13	19	0	0	19	in strips 11 and
	14	9	0	0	9	13 about 80 %.
	15	4	0	0	4	
	16	1	0	0	1	
	17	0	0	0	0	
	18	0	0	0	0	
	19	0	0	0	0	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	
	23	0	1	1	1	
	24	0	0	0	0	Visibility in
	25	0	0	1 G/Y	1	strip 28 about
	26	4	0	0	4	80 %. Staff
	27	2	0	0	2	gauge at bridge
	28	5	1	0	6	read 0.15 m.
6	1	0	0	0	0	
	2	3	0	0	3	
	3	0	0	0	0	
	4	2	0	0	2	
	5	0	0	0	0	
	6	8	0	0	8	Visibility at
	7	5	0	0	5	strips 6 and 7
	8	0	0	0	0	about 90 %.
	9	0	0	0	0	
	10	0	0	0	0	
	11	0	0	0	0	
	12	2	0	0	2	
	13	0	0	0	0	
	14	0	0	1 "R"	1	Actual color =
	15	1	0	0	1	R/G?
	16	0	0	0	0	
	17	1	0	0	1	
	18	0	0	0	0	
	19	6	0	0	6	
	20	0	0	0	0	Strip 20 about
	21	2	0	0	2	30 m wide.
	22	2	0	0	2	
	23	5	0	0	5	
	24	4	0	0	4	

Table A-3. (continued).

Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
6	25	1	0	0	1	
	26	4	0	0	4	
	27	2	0	0	2	
	28	4	0	0	4	
	29	0	0	0	0	
	30	0	0	0	0	
	31	1	0	0	1	
	32	2	0	0	2	

Table A-4. Calculation of numbers of sockeye spawning in six survey sections of Clemens Creek from strip-count data collected on 25 October 1988. Actual section lengths were determined by multiplying the distance between strips (33.5 m) by the no. of strips per section. Total fish/m was determined for each section by dividing the total number of fish observed by the total number of 1-m strips surveyed. Fish numbers in each section were then calculated by multiplying the total fish/m by the total-section length. Dead sockeye are included in all computations; therefore, the population estimate consists of live-plus-dead spawners.

Section	Length (m)	No. of Strips	No. of Sockeye Observed				Total Fish/m	Total Fish/ Section
			Live	Dead	Tagged[a]	Total		
1	871	26	75	0	2	77	2.96	2 578[b]
2	636	19	16	0	2	18	0.94	597
3	1 139	34	22	0	1	23	0.68	774
4	1 206	36	128	7	5	140	3.89	4 691
5	938	28	102	2	2	106	3.97	3 555
6	1 072	32	55	0	1	56	1.75	1 876
	Totals	175	398	9	13	420		**14 071**

[a] Data include only live sockeye.

[b] Spawner numbers were probably underestimated due to poor visibility at three stations where fish were abundant.

Table A-5. Petersen mark-recapture estimates of escapements to Henderson Lake in 1988 based on visual recovery data for live sockeye. The spawning population was estimated by both simple and stratified Petersen methods. The three weeks of tagging are represented by the tag applications of 1, 7, and 20 October respectively. The four weeks of recovery are represented by consecutive surveys beginning on 18 and 29 October, and 14 and 28 November, when tagged and untagged sockeye were enumerated on the spawning grounds. The numbers of tagged, live sockeye observed were adjusted upward by a factor of 2.84 to account for reduced visual detection efficiencies in 1988 due to the use of small-diameter tags (see text and Table 5).

		Weeks of Tagging			Tagged Fish Recovered (R_j)	Total Fish Recovered (C_j)	C_j/R_j
		1	2	3			
Weeks of Recovery	1	253	281	6	540	17 346	32.12
	2	62	57	199	318	5 758	18.11
	3	8	23	312	343	3 209	9.36
	4	0	0	3	3	118	39.33
Tagged Fish Recovered (R_i)		323	361	520			
Total Tagged Sockeye (M_i)		505	814*	1094			
M_i/R_i		1.56	2.25	2.10			

Simple Petersen Estimate: $(\Sigma M_i \times \Sigma C_j)/\Sigma R_{ij}$ = 52 972

Ninety-five Percent Confidence Interval: +3 078, -2 909

Upper 95 % Confidence Limit = N + 3 078 = 56 050
Lower 95 % Confidence Limit = N - 2 909 = 50 063

* Clear tags were excluded from this analysis.

Table A-5. (continued).

Stratified Petersen Estimate: 52 118

		Weeks of Tagging (i)			Total Sockeye Estimated Per Period (j)
		1	2	3	
Weeks of Recovery (j)	1	12 706	20 353	405	33 464
	2	1 755	2 327	7 581	11 663
	3	117	485	6 141	6 743
	4	0	0	248	248
Total Sockeye Estimated Per Period (i)		14 578	23 165	14 375	52 118

Ninety-five Percent Confidence Interval: +3 078, -2 909

Upper 95 % Confidence Limit = N +3 078 = 55 196
Lower 95 % Confidence Limit = N -2 909 = 49 209

Table A-6. Petersen mark-recapture estimates of escapements to Henderson Lake, 1988 based on recovery data for sockeye carcasses. The spawning population was estimated by both simple and stratified Petersen methods. The three weeks of tagging are represented by the tag applications of 1, 7, and 20 October respectively. The four weeks of recovery are represented by consecutive surveys beginning on 18 and 29 October, and 14 and 28 November, when dead sockeye were counted and pitched from the spawning grounds.

		Weeks of Tagging			Tagged Fish Recovered (Rj)	Total Fish Recovered (Cj)	Cj/Rj
		1	2	3			
Weeks of Recovery	1	13	8	0	21	205	9.76
	2	6	3	0	9	128	14.22
	3	11	14	33	58	2 085	35.95
	4	1	1	7	9	688	76.44
Tagged Fish Recovered (R_i)		31	26	40			
Total Tagged Sockeye (M_i)		505	844	1094			
M_i/R_i		16.29	32.46	27.35			

Simple Petersen Estimate: $(\Sigma M_i \times \Sigma C_j)/\Sigma R_{ij}$ = **78 226**

Ninety-five Percent Confidence Interval: +17 196, -14 095

Upper 95 % Confidence Limit = N + 17 196 = **95 422**
Lower 95 % Confidence Limit = N - 14 095 = **64 131**

Table A-6. (continued).

Stratified Petersen Estimate: **80 963**

		Weeks of Tagging (i)			Total Sockeye Estimated Per Period (j)
		1	2	3	
Weeks of Recovery (j)	1	2 067	2 535	0	4 602
	2	1 390	1 385	0	2 775
	3	6 442	16 337	32 445	55 224
	4	1 245	2 482	14 635	18 362
Total Sockeye Estimated Per Period (i)		11 144	22 739	47 080	**80 963**

Ninety-five Percent Confidence Interval: +17 196, -14 095

Upper 95 % Confidence Limit = N +17 196 = **98 963**
Lower 95 % Confidence Limit = N -14 095 = **66 868**